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July 2000

Silverleaf Whitefly

National Research, Action, and Technology Transfer Plan: Third Annual Review of the Second 5-Year Plan

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(Formerly Sweetpotato Whitefly, Strain B)
Third Annual Review of the Second 5-Year Plan, Held in San Diego, California, February 6–8, 2000

In cooperation with USDA/Agricultural Research Service, USDA/Cooperative State Research, Education, and Extension Service, State Agricultural Experiment Stations, USDA/Animal and Plant Health Inspection Service

Abstract

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Editors' Comments

Henneberry, T. J., R. M. Faust, W. A. Jones and T. M. Perring (eds.) 2000 Silverleaf Whitefly Supplement to the 5-Year National Research, Action, and Technology Transfer Plan (1997-2001). San Diego, CA, February 6-8, 2000.

This publication contains research, extension-education, industry and action agency reports of progress contributing to our knowledge of the whitefly complex and to the development of ecologically acceptable whitefly management systems. The multi-agency cooperative effort has, since 1992, provided a forum for information exchange, complementary, coordinated and cooperative research programs, avoidance of duplication of effort, and optimum return for expended research dollars. The result of the joint partnerships has been solutions and technology transfer to the stakeholders in the agricultural communities. These accomplishments have been achieved within a compressed timeframe, in large part, due to openness of communications, sharing of expertise and focus on common goals. The editors sincerely thank all those who participated in the second annual review of the new research and technology transfer plan.

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The USDA Silverleaf Whitefly, Research, Education and Implementation Coordinating Group; Annual Review Program Chairs; Local and State Coordinators; SLWF Program Planning and Review Committee; and the Silverleaf Whitefly Working Group sincerely appreciate the contributions of all the participants and those who have helped in organizing the 1999 meeting. Recognition is extended to the University of California Center for Exotic Pest Research for their support and cooperation in meeting site selection and program organization.

Preface

The Silverleaf Whitefly (SLWF), *Bemisia argentifolii* Bellows and Perring, National Research, Action, and Technology Transfer Plan (1997-2002)[1] was developed by USDA agencies (ARS, APHIS, and CSREES), state agencies, state agricultural experimental stations, and the cotton, vegetable, ornamental, nursery crop and chemical industries to establish research priorities, avoid duplication of effort, and maximize the use of existing resources. Research needs, goals and objectives, and technology transfer to clientele (scientific community, legislators, regulators, the agricultural industry, and the public) are reviewed on an annual basis. The plan is flexible allowing responsiveness to changing needs and priorities with appropriate adjustments to terminate, redirect, or add priorities based on funding, current knowledge, and program needs. The research objective is to develop environmentally and socially acceptable areawide, community-based silverleaf whitefly management methods.

The USDA Silverleaf Whitefly Research, Education, and Implementation Coordinating Group facilitates USDA interagency and partner state agricultural experiment stations activities. The Silverleaf Whitefly Working Group is composed of members of participating agencies and meets annually to maintain communication with the USDA Coordinating Group and the Silverleaf Whitefly Program Planning and Review Committee.

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Executive Summary

The third annual review of the Silverleaf Whitefly National Research, Action and Technology Transfer Plan documents a continuing federal, state, and industry cooperative effort to develop efficient management of *Bemisia* populations. The program was initiated in 1991 when working from a draft plan, representatives from federal and state agencies, agricultural experiment stations, industry and commodity groups identified five priority areas for development into a national research and action plan. At the end of the 1991 growing season, it was apparent that unacceptable losses in cotton and vegetable field crop production were being experienced in California, Arizona, Texas and Florida, as well as ornamental and vegetable losses in glasshouse. The need for "stop gap" control measures was urgent and addressed in the 1992 growing seasons. Standardized experimental procedures, data collection protocols, report preparation, and results exchange systems were established for a national testing program of promising chemicals, natural products, microbial insecticides and improved application technology for whitefly control on all major crops. Additionally, the framework for an insecticide-resistance management program (IRM) was established. Scientists in California, Texas, and Florida initiated laboratory studies to monitor insecticide responses of field populations to develop baseline information as a cornerstone for long-term IRM. The results of the national chemical control efficacy trials, with annual modification, improvement, and testing of additional materials have provided the basis for highly effective chemical control and ongoing IRM.

The action plan was designated "The Five-Year National Research and Action Plan for Development of Management and Control Methodology for the Sweetpotato Whitefly". The implemented high priority research areas were: (1) Ecology, Population Dynamics, and Dispersal; (2) Fundamental Research – Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions; (3) Chemical Control, Biorationals, and Pesticide Application Technology; (4) Biological Control; (5) Crop Management Systems and Host Plant Resistance; and (6) Integrated Techniques, Approaches and Philosophies.

Annual workshops were held to review progress and to adjust the plan as needed. After the annual review meeting in Orlando, FL in 1994, the titles of the reports of progress for the 5-year plan were changed to recognize the re-description of *Bemisia tabaci* strain B as a new species, *B. argentifolii* Bellows and Perring.

In 1996, final assessment of the initial 5-year plan was organized and a new 5-year plan developed for the years 1997-2001.

During the years 1992 to 1997, extensive research achievements were made that provided interim solutions and a better understanding of the whitefly problem. Some of the research accomplished as part of the plan has been implemented by growers in their management efforts. A complete published review of the program showed extensive progress in all priority research areas. Over 70

[1] The "5-Year National Research and Action Plan for Development of Management and Control Methodology for the Silverleaf Whitefly (formerly, sweetpotato whitefly, Strain B)" was initiated in 1992 and terminated in December 1996.

examples of technology transfer to growers and the scientific community were documented.

The second 5-year plan, "The Silverleaf Whitefly, (*Bemisia argentifolii* Bellows and Perring) Research, Action and Technology Transfer Plan" was finalized at the annual review meeting at San Diego, CA on January 28-30, 1997. The high priority research areas are: (A) biology, ecology, and population dynamics; (B) viruses, epidemiology and virus-vector interactions; (C) chemical control, biopesticides, resistance management, and application methods; (D) natural enemy ecology and biological control; (E) host plant resistance, physiological disorders, and host-plant interactions; and (F) integrated and areawide pest management approaches, and crop management systems.

Introduction

The silverleaf whitefly *Bemisia argentifolii* Bellows and Perring [*B. tabaci* (Gennadius) Strain B] has risen in status as a major pest of world agriculture. Increased globalization of agriculture and floriculture and international transport of plant material have contributed to the introduction of variant forms of *Bemisia* and associated plant viruses to regions where they were previously unknown. Economic losses have been estimated in the hundreds of millions of dollars in some affected areas. Whitefly management efforts have been generally successful, but require higher costs and increased vigilance to avoid outbreaks of the magnitude observed in the early 1990s in certain regions of the southwestern USA. Crop losses due to vectored viruses recently introduced into new areas or characterized and described for the first time have also contributed to the problem. Establishment of virulent whitefly biotypes and viruses continues in new geographical areas and emphasizes the need for greater focus on *Bemisia* as a serious crop pest and virus vector.

Various biological traits of the silverleaf whitefly, including a broad host range, contribute to rapid population expansion during favorable seasons. In addition to climatic factors such as temperature, humidity and rainfall, the quality and quantity of food resources also influence population growth. The types of crops grown, their relative acreages and phenologies during the annual crop cycle together with wild and ornamental hosts are also important in population dynamics. Dispersal between fields or relocation to preferred hosts work in concert with its polyphagous nature to increase population densities in a multiple crop environment. High fecundity levels, coupled with fast developmental rates, help define an organism with a high intrinsic rate of increase and the capability to rapidly colonize a potential food source. Silverleaf whitefly is broadly tolerant of harsh environmental conditions and routinely survives and sometimes flourishes in desert climates that may range between –2 to 50° C. It is also highly adaptable to extreme stress factors such as insecticides as evidenced by the multiple mechanisms of resistance that have evolved in populations around the world. How these traits are expressed in various environments strongly influences population growth and infestation levels in crops.

Natural and applied population regulating factors also impact silverleaf whitefly population development. The insect has often been considered as an 'upset' pest, induced to damaging crop levels through misuse of insecticides. There are many well-documented cases of insecticide resistance that argue for integrated management and non-chemical measures to suppress populations. However, some crop environments may represent conditions that are optimal for whitefly population growth, thus natural control factors may be overwhelmed, leaving little choice but to counter with chemical measures. The key to successful management of any agricultural pest is understanding its intrinsic potential for increase in various environments while also knowing the capacity of countermeasures to suppress population growth. More information on the biology and population dynamics is becoming available as the silverleaf whitefly gains importance in additional regions. A major objective of the silverleaf whitefly national research, action and technology transfer plan is to encourage collection and implementation of existing information into management systems and encourage cooperative efforts to identify existing research needs essential to the development of socially, environmentally and economically acceptable silverleaf whitefly management.

Table 1. Numbers of Research Abstracts for the 1998-1999 Silverleaf Whitefly Annual Progress Review of the USDA Silverleaf Whitefly National Research, Action and Technology Transfer Plan (1997-2001).

Agency[b]/State	A	B	C	D	E	F	Total
			Research Priorities[a]				
			1998 Review, Charleston, SC				
APHIS				11			13
ARS	12		6	13	6	1	38
AZ			1			2	3
CA	1	1	7	5	6	3	23
FL	1	1			1		3
GA					1		1
NY							
OH							
TX				2			2
OTHERS	3			1	1	1	6
TOTAL	17	2	14	32	15	9	89
			1999 Review, Albuquerque, NM				
APHIS				3		6	9
ARS	16	3	6	4			29
AZ	1			3		4	8
CA	1	1	5	5	6		18
FL			1				1
GA							
NY							
OH							
TX	1	4	5				10
OTHERS	5	1	1	3	3	2	15
TOTAL	24	5	17	23	9	12	90
			2000 Review, San Diego, CA				
APHIS				2			2
ARS	15	1	6	7	2	2	33
AZ							
CA	2	1	5	5	7	1	21
FL		1					1
GA							
NY							
OH							
TX		1	1	1	1	1	5
OTHERS	3	2		9		3	17
TOTAL	20	6	12	24	10	7	79

[a] A = Biology, Ecology, and Population Dynamics; B = Viruses, Epidemiology and Virus-Vector Interactions; C = Chemical Control, Biopesticides, Resistance Management, and Application Methods; D = Natural Enemy Ecology, and Biological Control; E = Host-Plant Resistance, Physiological Disorders, and Host Plant Interactions; F = Integrated and Areawide Pest Management Approaches, and Crop Management Systems.

[b] APHIS = USDA, Animal and Plant Health Inspection Service; ARS = USDA, Agricultural Research Service.

BRIEF HISTORY, RESEARCH PROGRESS, AND CURRENT PEST STATUS OF *BEMISIA* IN THE UNITED STATES

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Bemisia tabaci (Gennadius) was first found in the United States on sweetpotato, *Ipomoea batatus* (L.), in Florida in 1894 (see Henneberry et al. 1998 for review). It was not implicated as an economic pest until 1954 when it was identified as the vector of a geminivirus causing cotton leaf crumple disease in California. The leaf crumple problem persisted during 1954 to 1961. It was solved by eliminating rattoon cotton as the virus reservoir and *B. tabaci* reverted to non-economic pest status. *Bemisia* populations increased dramatically in the late 1970s in California and Arizona causing severe damage in squash, melons, cotton and other crops. Losses in 1981 exceeded 100 million dollars. Problems continued through the mid and late 1980s and reach epidemic proportions in the 1990s in California, Arizona, Texas and Florida causing losses estimated to exceed 200 million dollars annually in field and greenhouse production. Atypical behavior, host adaptation, occurrence of plant physiological disorders, and genetic differences of *Bemisia* populations in the late 1980s resulted in the description of *B. tabaci* Biotype B and later redescribed as a new species and named *B. argentifolii* (Bellows et al. 1994).

Epidemic *Bemisia* populations in California and Arizona that characterized the late 1980's through the mid-1990s have not occurred in the growing seasons of 1997, 1998 and 1999 as a result of implementing our increased knowledge of the pest in developing control methodology. However, advances in *Bemisia* control technology have not been attained without increasing control costs and agricultural community involvement. In Arizona, California and Texas cotton, action thresholds and two new chemistry insect growth regulators (Applaud and Pyriproxyfen) in combination with cultural control have been very effective for managing populations. The insect growth regulator treatment costs are about 35 dollars per acre but crop yield and quality have been adequately protected. In Imperial Valley, California, cotton production was reduced from 15,000 acres in 1990-1991 to 4 to 5,000 acres in the early 1990s and has increased to about 8,000 acres in 1998 and 1999 because of the new technology. Similarly, a new chemistry-systemic insecticide (Admire) has consistently provided excellent *Bemisia* control on melons and vegetables, but costs are $65 dollars per acre. In California, Arizona and Texas almost all melon acreages, of necessity, are treated with Admire to protect from *Bemisia* infestations. Applaud has been registered for *Bemisia* control on melons and cross commodity cooperation has been developed to avoid *Bemisia* exposure to Applaud resistance selection pressure in overlapping melon and cotton growing seasons. The increased costs associated with administrative coordination, increased monitoring, and resistance management programs are extensive. In Imperial Valley, as a result of whitefly populations, spring melon acreages were eliminated in the early 1990s and continue to be reduced from the average of 25 thousand acres in the pre-1990s to about 14 thousand acres in 1999. Fall melons were grown on 10 thousand acres in 1990 and on 2 thousand acres in 1998-1999. The indirect economic effects of *Bemisia* infestations through reduced acreages has also occurred in other ways. Although new insecticidal chemistries have played a major role in providing *Bemisia* control in many of our major cropping systems, high cost may limit their use under some circumstances. For example, growers of some specialty crops on small acreages and targeted for limited markets may not, because of the high price, be able to take advantage of the new technology because the expense outweighs profit return. Often in these cases the crop is simply no longer grown commercially in the area where *Bemisia* is a problem. Extensive documentation of these cases does not exist, but termination of fall squash production in Imperial Valley as related to *Bemisia*-transmitted squash leaf curl virus was a case in point (Agricultural Commissioner's Office, Imperial Valley, CA, Personal Communication).

Additionally, the occurrence of new virus-induced plant diseases, the causal agents transmitted by *Bemisia*, have been on the increase for the last several years. In Southern California a new whitefly-transmitted geminivirus affecting cucurbits was found in 1998 and also recently detected in Arizona (E. Natwick, Univ. CA Farm Advisor, Holtville, CA; Personal Communication). The long-term impact is unknown but past experience suggests that the situation must be monitored closely. *Bemisia* populations in Texas have also declined from epidemic levels that were experienced in the early to mid 1990s. However, cantaloupe and honeydew melons in the lower Rio Grande Valley have been identified as having *Bemisia*-transmitted Cucurbit Stunting Disorder Virus (CYSDV) disease (Liu et al. 2000). The occurrence of the closterovirus is of much concern to melon growers and its spread, persistence and economic impact will be followed closely. Economic losses have already been experienced. In Florida, the *Bemisia* virus vector activity is also being experienced (Polston 1999). Symptoms characteristic of Tomato Yellow Leaf Curl Virus (TYLCV) were first observed on a few tomato plants in the field and nurseries in 1997. The virus probably entered the U.S. in 1996 or 1997 and was rapidly distributed via retail garden centers around the state.

Regulatory procedures, that are highly costly, as well as field management practices have been implemented to minimize the movement of the virus. Even so, TYLCV has spread throughout the state since its first identification. Yield losses have been experienced as well as increased production costs. Pesticide applications to minimize whitefly populations have increased. New regulations have been imposed on transplant producers of known TYLCV host plants, which include lisianthus (*Eustoma grandiflorum*), tobacco (*Nicotiana tabacum*) and tomato, to minimize the occurrence of TYLCV in certified transplants. TYLCV has been demonstrated to have a devastating effect on tomato yield, particularly when plants are infected in early stages of development. The long-term impact on tomato production in Florida remains unknown.

In summary, intensive research since the mid-1980s has provided short-term relief from the devastating impact of explosive *Bemisia* populations. Effective *Bemisia* management has been accomplished within the framework of (1) selection of non-preferred cultivars, (2) spatial and temporal considerations in sequential crop systems, (3) intensive sampling and monitoring of whitefly populations, (4) chemical control focused on natural enemy conservation, established action thresholds, alternating chemistry, new chemistry, and resistance monitoring, (5) optimum crop yield goals allowing for early harvests and destruction of crop residues, and (6) active education, extension outreach to provide timely communications of new developments, SPW population dynamics, and other pertinent information to growers. Additionally, this research has resulted in a huge base of information on whitefly biology, ecology, behavior and physiology has been added to improve our knowledge for formulating long-term strategies for management. Even so, currently, the most common approach to *Bemisia* control is the use of insecticides alone or in mixtures. The associated environmental and social problems as well as the occurrence of insecticide resistance have been anticipated and ameliorated somewhat by the use of developed action thresholds and Insecticide Resistance Management (IRM) programs. Chemical control and IRM have been highly effective on a short-term basis. Experience has taught the entomological community that the probability of continuing long-term insecticide based management efficacy is remote. Thus, continuing efforts are needed to develop areawide, community-based *Bemisia* management systems that incorporate cultural, biological, and nonchemical methods into chemical control-IRM-based control methods.

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II. Plenary Session Keynote Address Summaries

Section A: Plenary Session Summary

Investigator's Name(s): Linda L. Walling

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Research & Implementation Area: Section A: Biology, Ecology and Population Dynamics

Dates Covered by the Report: 1996–1999.

New Genes and New Signals: The *Bemisia argentifolii* -Squash Interaction

Many previous studies in plant defense have concentrated on either responses to wounding, pathogen infections or responses to chewing insects. To determine the nature of plant responses to phloem-feeding insects, we have studied whitefly interactions with tomato and squash plants. Tomato-whitefly interactions were attractive to study given the availability of genes that are activated by pathogens or mechanical stress. We compared changes in tomato gene expression following feeding by two species of whiteflies: *Bemisia argentifolii* Bellows and Perring (the silverleaf whitefly) and *Trialeurodes vaporariorum* Westwood (the greenhouse whitefly). In response to pathogens, defense-response genes are activated by salicylic acid (SA), reactive oxygen species (ROS) or a combination of jasmonic acid (JA) and ethylene. RNA blot analyses showed that pathogenesis-related (*PR*) protein genes regulated by both JA/ethylene and SA are activated after feeding by both species of whiteflies. Both local and systemic accumulation of *PR* RNAs were observed. RNAs for *PR* genes regulated by JA/ethylene (basic chitinase, basic β-1,3-glucanase, PAL) accumulated to the highest levels. Increases in the RNAs for *PR* genes regulated by SA (acidic β-1,3-glucanase, acidic chitinase) were also detected but these RNAs were not as abundant. Wound-response gene RNAs (leucine aminopeptidase and proteinase inhibitor) were not detectable. In addition, transgenic tomato plants expressing a *LapA* promoter:*GUS* fusion gene were used to further elucidate the wound response following whitefly feeding. Whitefly feeding did not induce a wounding response.

Novel genes induced by whitefly feeding were identified by differential RNA display. After feeding by the silverleaf and greenhouse whiteflies, transcripts for a JA/ethylene regulated *Wfi1* gene was identified. *Wfi1* encodes a subunit of the NADPH oxidase that is involved in generation of superoxide anion in the plant oxidative burst. The studies on this gene are more completely described in Puthoff et al (this volume). Interesting, *Wfi1* is induced by whitefly but not aphid feeding. These data suggest that the signals generated by these different phloem-feeding insects may be different.

Interactions between squash plants and the silverleaf and sweetpotato (*B. tabaci* Type A) whiteflies were also examined in order to understand the similarities and differences in plant responses to feeding by two closely related species of whiteflies. Silverleaf whitefly nymphs induce the squash developmental disorder called leaf silvering, while silverleaf whitefly adults and sweetpotato whitefly nymphs and adults do not. For this reason, differential RNA display was used to identify squash genes preferentially induced by the silverleaf whitefly and not the closely related sweetpotato whitefly. Genes induced in apical, non-infested silvered leaves after silverleaf whitefly (*Bemisia argentifolii*) feeding were isolated. The identification of genes expressed in apical, silvered leaves from silverleaf whitefly-infested plants and not expressed in leaves of similar age from sweetpotato whitefly-infested plants may allow the identification of defense-response genes that are systemically expressed. Alternatively, the genes may be involved in the establishment, maintenance or as a response to leaf silvering. Two genes (*SLW1* and *SLW3*) preferentially induced by the silverleaf whitefly have been identified. The expression and characterization of *SLW1* was detailed in van de Ven et al. (this volume).

SLW3 was regulated in a different manner than the JA/ethylene regulated *SLW1*. Temporal and spatial expression studies showed that *SLW3* RNAs accumulated only after nymph feeding. *SLW3* RNAs accumulated in more distal leaves only in response to silverleaf whiteflies, not in response to sweetpotato whitefly feeding. *SLW3* RNAs also accumulated in infested leaves from silverleaf and sweetpotato whitefly infested plants and in the leaves most proximal to the infested leaves. These data suggest that *SLW3* may be regulated by two sets of signals. One set of signals may induce local expression by both whitefly species. A second set of signals in silverleaf whitefly-infested plants may induce expression in the most distal leaves. Alternatively, the same signal may induce local and systemic expression but this factor must be less potent, produced in lower quantities or transported inefficiently in sweetpotato whitefly infested plants. Unlike *SLW1*, which is expressed in both flowers and fruit, *SLW3* RNAs were not detected in any organ examined. Silverleaf and sweetpotato whitefly infestations did not alter this developmental programming. *SLW3* encodes a β-glucosidase-like protein and is regulated by a novel defense-signaling pathway. *SLW3* RNA levels were not influenced by *Pseudomonas syringae* pv *syringae* infection, wounding, MeJA, ethylene, SA, ABA, hydrogen peroxide or nitrous oxide treatments. These data indicate that *SLW3* is not activated by the known defense- or wound-signaling pathways, which are characterized in tomato and *Arabidopsis*. The source of

the signal that activates *SLW3* expression is not known. It may be of insect, endosymbiont or plant origin. Alternatively, it may be synthesized by the coordinate activities of the insect and plant, as has been seen for the volatile-inducing elicitor volicitin. Interestingly, *SLW3* RNAs accumulated to high levels in response to water-deficit stress suggesting that *SLW3* is regulated by two different signaling pathways or there is overlap in the signals generated by whitefly feeding and water-deficit stress.

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Section B: Plenary Session Summary

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Research & Implementation Area: Section B: Viruses, Epidemiology, and Virus Vector Interactions.

Dates Covered by the Report: 1997–1999.

Tomato yellow leaf curl geminivirus (TYLCV-Is), a sexually transmitted disease of the whitefly *Bemisia tabaci* (*B. argentifolii*)

Geminiviruses constitute the most important class of pathogens transmitted by *B. tabaci* Their single-stranded DNA (ssDNA) genome is encapsidated in ~ 20 x 30 nm geminate particles. Whitefly-transmitted geminiviruses (family *Geminiviridae*, genus *Begomovirus*) infect many economically important agricultural plants. Among them, tomato yellow leaf curl virus (TYLCV) has probably the most serious economic impact.

Begomoviruses and whiteflies have interacted for geological times. Multiple repeats of modern begomoviral-related sequences were found integrated in a single chromosomal locus of several *Nicotiana* species, suggesting that a unique geminiviral integration event occurred more than 100 MY ago. Fossil whitefly species, though not *B. tabaci*, have been found in 120-140 MY old amber from Lebanon. An assumed long-lasting virus-vector intimate relationship of this magnitude implies that the partners have developed co-evolutionary mechanisms that insure on one hand the survival and the efficient transmission of the virus, and on the other hand the safeguard of the insect host from possible deleterious effects of the virus. Novel data from our lab suggest that TYLCV-Is has retained, or acquired, some characteristics of an insect pathogen.

The whitefly *B. tabaci* acquires and transmits TYLCV-Is in a circulative manner. During the 8 h-long latent period, the ingested virus circulates in the insect along a path and with a velocity likely shared by all begomoviruses. Bacteria that have lived in symbiosis with *B. tabaci* for more than 100 MY are involved in the safe translocation of begomoviruses in *B. tabaci*. A GroEL chaperonin synthesized by *B. tabaci* endosymbiotic bacteria and released into the insect haemolymph ensures the safe transit of TYLCV-Is in the insect haemolymph. Disturbing this virion-GroEL interaction in the haemolymph lead to the destruction of virus particles and subsequently to a dramatic decrease in virus transmission (1).

Begomoviruses acquired during a short period of time by 1-2 day-old *B. tabaci* adults remain associated with the insect for several weeks. TYLCV-Is was present during the entire life of the insect (2). Although infectivity decreased with age, the insects were able to infect test plants for more than 4 weeks. Therefore, at least some of the acquired virions are able to remain as infective units, or to return, into in the circulative pathway several weeks after acquisition. It is likely that a large fraction of the ingested virus leaves the acquisition/ transmission pathway and invades insect tissues. This long-term retention of TYLCV-Is in its whitefly host was associated with a dramatic decrease in the life expectancy of the host and in its fecundity.

Invasion of tissues by TYLCV-Is and its effect on the insect fecundity was demonstrated for the reproductive system. The long-time retention of TYLCV-Is was accompanied by a ~ 40% decrease in the mean number of eggs laid by whiteflies. These negative effects were expressed several days after acquisition, as if the virus had first to invade the reproductive system and aborting part of the developing eggs laid (2). Indeed, eggs maturing in the ovaries of viruliferous whiteflies contained viral DNA detectable by PCR. Viral DNA was similarly detected in some of the adult insects that developed from these eggs (3). The way in which TYLCV penetrates the whitefly reproductive system is unknown. We presume but we do not have direct proof that TYLCV-Is invades tissues others than those of the reproductive system. Virus invasion may account for the reduction observed in the life span of viruliferous whiteflies compared to non-viruliferous insects. In both winter and summer, the viruliferous insects started to die earlier and at higher rates (up to day 30) than their non-viruliferous counterparts. As a result, the life expectancy of the viruliferous insects was significantly lower than that of the non-viruliferous

controls. At the population level, the difference at the 50% mortality point was between 5 and 7 days (2).

Because TYLCV-Is had several characteristics of an insect virus, we investigated the possibility that it could be transmitted horizontally, from insect to insect, without the mediation of an infected plant. TYLCV-Is was transmitted among whiteflies in a sex-dependant manner, in the absence of any other source of virus. TYLCV was transmitted from viruliferous males to females and from viruliferous females to males, but not among insects of the same sex. Transmission took place when insects were caged in groups or in couples, in a feeding chamber or on cotton plants, a TYLCV-non-host. The recipient insects were able to efficiently inoculate tomato test plants. Insect to insect virus transmission was instrumental in increasing the number of whiteflies capable of infecting tomato test plants in a whitefly population. TYLCV was present in the haemolymph of whiteflies caged with viruliferous insects of the other sex; therefore the virus follows, at least in part, the circulative pathway associated with acquisition from infected plants. Taken as a whole, these results implicate that a plant virus can be sexually transmitted among its insect vector.

Infection of plant hosts by begomoviruses is still not fully understood although the function of the geminiviral genes has been thoroughly investigated for the last decade. The way begomoviruses interact with their insect vectors is even less understood. The days when it was thought that whiteflies are mere go-between are gone. A begomovirus such as TYLCV-Is has many features of an insect virus. It is likely that this virus is not the only one with such extraordinary properties. Others may have retained, or gained, some pathogenic features during their co-evolution with *B. tabaci* which remain to be discovered.

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Section D: Plenary Session Summary

Compiled by: James Hagler

Presentation by: John Heraty (University of California, Riverside) and Mike Rose (Montana State University).

The keynote address for Section D, Natural Enemy Ecology and Biological Control, was a joint presentation given by John Heraty (University of California, Riverside) and Mike Rose (Montana State University). John Heraty discussed the morphological, molecular and taxonomic perspectives on *Encarsia* (Hymenoptera: Aphelindiae). *Encarsia* is a diverse and cosmopolitan species that is parasitic on whiteflies, armored scales, or themselves (autoparasitoids). At present there are more than 200 described species of *Encarsia* and new species are continually being described or recognized. The genus *Encarsia* represents one of the most important parasitic groups being used in biological control, and various species are currently being collected as part of foreign exploration efforts to search for biological control agents. New programs are focusing on the control of *Bemisia* with *E. strenua* and *E. transvena*, and on citrus whitefly in California with *E. variegata*. Biological and taxonomic characteristics remain poorly known even for common species of *Encarsia*.

Many species of *Encarsia* are undescribed. However, we must be able to accurately recognize species with the greatest potential for control. A common assumption is that closely related species may share similar habits and host preferences to known species and are therefore desirable candidates for biological control. These relationships are most commonly determined by the presence of shared derived morphological characters. Unfortunately, species groups of *Encarsia*, which are our first approximation of related species, are often defined by combinations of characters, many of which are characteristic of one or more species placed in other species groups. Even obvious group characteristics are found in unrelated groups of species; for example, the close placement of scutellar sensilla, which were considered diagnostic of the *strenua* -group, are now known to be convergent and found in several very unrelated groups of species.

Understanding the species groups of *Encarsia* is of primary importance to biological control. Currently, species are grouped arbitrarily on the basis of overall similarity. This can lead to misconceptions about behavior and host associations that are crucial for biological control programs. Analysis of morphological characters has led to differing opinions as to the relationships, composition and placement of species into groups of *Encarsia*.

Molecular systematics (comparing species based on their genetic similarities) offers a new character system that

can be used to evaluate present concepts of species relationships. Although severely limited by the number of taxa that can be sampled, the analysis of nucleotide sequences can be used to test the relationships of existing groups and, perhaps more importantly, evaluate the morphological characters used to define those groups. This latter point is probably the most relevant for sorting field-collected material in biological control programs.

Mike Rose discussed his research on *Eretmocerus*, a key parasitoid of *B. argentifolii*. *Eretmocerus* (Hymenoptera: Aphelinidae) are important natural enemies of whitefly. Species of *Eretmocerus* are primary, solitary ecto/endo parasites with demonstrated searching ability that inflict high mortality on hosts by parasitization, mutilation, and host feeding. Characters of the genus were presented and illustrated, as were characteristics used to describe and differentiate different *Eretmocerus* species. Additionally, examples of *Eretmocerus* species diversity were shown, and examples of both historic and current taxonomy in the genus were illustrated.

Section F: Plenary Session Summary

Investigator's Name(s): Steve E. Naranjo[1] & Peter C. Ellsworth[2] (Part I)
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Research & Implementation Area: Section F: Integrated and Areawide Pest Management Approaches, and Crop Management Systems.

Dates Covered by the Report: 1996–1999.

Whitefly Population Dynamics: Why Use Life Tables & What Do They Tell You?

Studies of population dynamics of any species seeks to explain the underlying mechanisms and consequences of changes in population density. Population density is a function of births, deaths, immigration and emigration. Studies into these questions may be descriptive, theoretical, experimental or demographic. For the past four years we have endeavored to use the demographic approach known as life tables to describe, explain, and contrast whitefly population dynamics in managed and unmanaged cotton systems.

Life tables quantify the probability of dying while assigning a specific cause of death. Underlying mechanisms of population change may be inferred by study of these mortality rates by insect stage (age) and/or by mortality factor. Using procedures that adjust for contemporaneous mortality, marginal rates can help identify the relative importance of various mortality factors in population change. From this, we can conduct K-factor analyses, estimate irreplaceable mortality, and make specific experimental treatment contrasts.

The identification of these factors within IPM systems is crucial to understanding how that system functions to control whiteflies. By contrasting to unmanaged cotton systems, we can demonstrate the role that each mortality factor (and insect stage) plays in regulating population density. We can infer how and when specific insecticides work (conventional and insect growth regulators [IGR]) and when biological control agents might be most compatible with other management practices, especially chemical controls.

Under large plot replicated conditions (>0.25 ha/plot) in Maricopa, AZ, four different whitefly management 'regimes' were implemented (Knack® used first, Applaud® used first, non-IGR conventional chemistry, and an untreated check [UTC]). To monitor insecticidal inputs for Lygus control, split-plots were established each year (1997–1999) such that a Lygus-untreated and treated split were maintained throughout the season. The final key pest of this system, pink bollworm, was managed through the use of *Bt* transgenic cotton throughout all studies. No other insecticides were required for any other pests.

Over 14 whitefly generations (1997–1999) in unmanaged cotton (UTC), generational survivorship (egg–adult) ranged from 0% to 27%. Sources of mortality included obvious predation (usually from sucking predators), parasitism (apparent in the 4th instar by *Eretmocerus* or *Encarsia* spp.), 'missing' (which is a factor that partitions among predation, weather-related or insecticide-related dislodgement), unknown (which may be related to physiological mortality), inviability (which was in the egg stage only and refers to lack of hatching), and "sunken" (an unknown factor that resulted in a typically sunken, intact, fourth instar). Marginal rates of mortality over this period showed the following order for factors (highest to lowest): predation > missing > unknown > inviability > parasitism; and for stage-specific rates: egg > N4 > N3 > N2 > N1. Irreplaceable mortality, or that mortality which could not otherwise be replaced by some other contemporaneous factor, showed the following patterns of importance (highest to lowest) by factor: predation > missing > unknown > inviable > parasitism. K-factor analyses which estimates the importance of a single mortality source or stage on the overall generational mortality showed the following order of importance (highest to lowest) by factor: inviable > missing > predation > 'sunken' > unknown > parasitism; and by stage: egg > N4 > N2 > N1 > N3.

These analyses point to the importance of egg inviability to the overall dynamics of whitefly populations in unmanaged cotton. They also show the relative minor

impact that parasitism has on whitefly population dynamics. Predation, meanwhile, plays a significant role especially when considering that a portion of the 'missing' category was likely as a result of removal by predators. The prominence of 'missing' as a source of mortality is also of interest. High rates of 'missing' were noted following major weather disturbances associated with the summer monsoon season. Nymphs and even eggs were removed by high winds, dust, and/or rain over the course of these studies.

Whitefly population dynamics were simulated using an unpublished whitefly model (Naranjo, DeGrandi-Hoffman, unpubl) and the specific measured rates of mortality over 4 to 6 successive generations within a year. Where the observed deviates from the model prediction, we might infer the effects of adult movement. In each year simulated, the first generation simulation underpredicts the actual measured adult densities. The discrepancy is likely at least partly due to the immigration of adults from sources external to cotton early in the season. Likewise in the late season, the fourth or fifth generation simulation overpredicts the actual adult densities measured. This would suggest the effects of emigration, when cotton develops through to cut-out and ceases to be an attractive host for whitefly adults. The intervening generations were extremely stable, i.e., there were no apparent deviations between the predicted and observed densities and thus little presumed effects of migration.

Synthetic survivorship curves made up of the 6–12 generations of whiteflies treated or untreated with insecticides show just how fragile a state the 'managed' condition is relative to unmanaged. The difference between the two curves implies the impact of insecticides on the system. Somewhat counter-intuitively, the gap between curves is rather low with only a 2% difference in survivorship to adulthood. Thus, it would seem that IPM is challenged to achieve a rather "minor" level of irreplaceable mortality in order to accomplish economic control of this insect.

Chemical control (including IGRs) has been dramatically successful in the campaign to manage whiteflies in Arizona. Yet, our results from unmanaged cotton would suggest that they are assisting with only an extremely small amount of irreplaceable mortality. *In situ* life tables provide us the tools necessary for identifying and quantifying these changes from the unmanaged condition. Marginal, stage-specific mortality from insecticides clearly identify the mode of action of the respective chemistries used. Knack provided 4–38% marginal mortality in the egg stage and was the only compound that had significant insecticidal effects on that stage. Applaud had the highest rates of marginal mortality in the young instars (N1 & N2), while the conventional chemistry was capable of killing some younger instars. Insecticide mortality was not a major factor in the larger instars, though Knack and conventional chemistry had appreciably higher rates of marginal mortality than Applaud. Knack, as a juvenoid, is known to affect egg viability and metamorphosis in N4. Applaud, a molting inhibitor, disrupts the instar transitions up to but excluding N4.

The other major feature of the IGRs, however, is their selectivity towards whiteflies. This feature is thought to enhance or at least conserve the extant predator populations. Our studies of egg cohorts over each year show differing contributions of insecticides vs. predation effects on mortality. They do, however, show a consistent trend of higher rates of marginal mortality due to predation in the IGR regimes when compared to the conventional chemistry, yet similar to the UTC. This general trend was observed for the nymphal stages as well; however, it was much more pronounced and consistent one generation post-application of the IGRs.

Management of whiteflies at the same location with the same conventional chemistry since 1995 has revealed a different spray requirement for whitefly control each year (1–6 sprays). Clearly, different forces were acting on these populations each year. Yet every year populations initially reached the recommended threshold with a population fate or trajectory of unknown consequence. This presents growers and practitioners with a critical challenge. That is, the ability to predict the whitefly population dynamics in the context of all interrelated mortality factors, including insecticides. Grower experience tells us that the IGRs "last" 30 days or more. Our work which directly measures insecticidal mortality clearly indicates that the bulk of insecticide mortality occurs during the first 14 days. Little if any IGR-related mortality occurs beyond this point. What then is the source of this additional mortality? Our results would suggest that the IGRs provide for an environment where predation can occur at rates similar to untreated cotton. Thus, when predators are abundant, growers can expect a large contribution of predation to the "bioresidual" of the IGRs. When predators are low, however, these effects maybe less dramatic, such as when a broad-spectrum insecticides are required for Lygus control. Looking at insecticide-related effects over 8 generations, irreplaceable mortality rates are surprisingly low (0.001–0.08). This re-enforces the fact that insecticides are providing for an exceedingly small, yet strategic source of mortality, and that with the IGRs an additional boost is provided by the natural enemies that are conserved.

Ultimately, an IPM plan has been implemented that includes a significant component of chemical control. *In situ* life table analyses have helped explain when and why the current approach is successful and may be pointing to additional opportunities for control of whiteflies within the cotton system. There are, however, significant limitations to this approach. First, it's hard work! Direct observation under field conditions over long summer

periods demands the discipline and training necessary to routinely and carefully identify sources of mortality, insect age, and time of death in the field. Importantly, too, our studies represent in this case 14 different snapshots in time, and extension to other periods or other generational starting points might produce different results. For example, all of our first post-spray cohorts were marked and initiated 1-day post-application. Strictly speaking, our life tables remain incomplete, because they lack any direct estimates of crawler mortality, the 12 hr long ambulatory stage of the first instar. The duration is so short that its impact may be minor; however, anecdotal evidence would suggest that crawlers are subject to conventional insecticides and weather-related dislodgement. Finally, no effort was made to assess adult mortality directly or the impacts of immigration and emigration, though our work can assist in assessments of adult movement.

The power of our approach has yielded some important findings with respect to IPM and biological control. Insights derived from the life tables provide explanation for the large annual variation observed in whitefly population dynamics in Arizona cotton. The specificity and modes of action of the IGRs were identified and quantified. Through the use of simulation our results provide for new hypotheses about the effects of immigration and emigration in the system. Weather as a source of mortality in whiteflies has been discovered, described, and quantified. Even as uncontrollable and unpredictable as this source may be, its impact on the system was fairly consistent over years. It certainly re-enforces the recommendation to hold-off chemical controls if a significant weather event is imminent. Most importantly, however, to IPM, we have a systems level evaluation in which extrapolation and modeling are unnecessary. Mortality was measured directly and *in situ* within production systems of relevance to growers in the West. Ultimately, life tables become a powerful tool for measuring the bioefficacy of novel compounds and other management tactics.

In terms of biological control, there are a number of important conclusions. Most interesting is the relatively weak role that parasitoids have, even in unmanaged cotton systems here. This fact calls into question even the measurement systems that are most widely used to assess "parasitism rates." Predation and 'missing,' on the other hand, were major sources of mortality in both managed and unmanaged systems. Thus, tactics which capitalize on this fact, such as selective IGRs, result in better natural enemy conservation and ultimately better control. This, too, re-enforces the recommendations for IGR use to growers which includes 1) use them first instead of broad-spectrum chemistry, 2) do not tank-mix with broad-spectrum chemistry, and 3) provide for enough time to see their effects and maximize their "bioresidual" through natural enemy conservation.

Reports of Research Progress

Section A: Biology, Ecology, and Population Dynamics
Co-Chairs: Tom Perring and Michael Salvucci

Investigator's Name(s): Jacquelyn L. Blackmer[1], Elizabeth W. Davidson[2], & Linda L. Lee[1].

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Research & Implementation Area: Section A: Biology, Ecology and Population Dynamics.

Dates Covered by the Report: December 1998 – December 1999

Evaluation of Artificial Diets for Rearing *Bemisia tabaci* (Biotype B) (Homoptera: Aleyrodidae)

Bemisia tabaci (Biotype B), also known as *B. argentifolii* Bellows & Perring, is one of the principal pests of food and fiber crops. In 1990, a change in feeding behavior, an expanded host range, and rapidly developing resistance to insecticides made this species the primary autumn pest in the southwestern USA. Despite the important pest status of *B. tabaci*, very little is known about the nutritional ecology of this insect. Understanding the role that nutrients, phagostimulatory cues and/or feeding deterrents have in whitefly host selection and acceptance, growth and reproduction could lead to the development of plant genotypes resistant to whiteflies, as well as provide information that might be useful in explaining whitefly distributions and outbreaks. The objectives of our studies were to optimize a recently developed meridic diet, which could be used as a standard for comparison, while various holidic diets were examined for their suitability in sustaining whiteflies through to the adult stage. A polycarbonate feeding chamber, equipped with a Teflon membrane, was used to test a series of diets that evaluated the effect of sucrose concentration (10-30%), diet pH (6.5-8.0), the ideal number of eggs/chamber(<50->600) and the optimal egg age (3-9 d) on hatch rate, development and emergence rates of *B. tabaci*. Hatch rates and survivorship were significantly higher for diets with sucrose concentrations of 15-20%, when compared to diets containing 10 and 30% sucrose. Response to diet pH was variable. Survivorship was initially higher on diets with a pH of 6.5-7.0 than on diets with a pH of 7.5-8.0, but by Day 10 this difference was negligible. Five- to six-day-old eggs had a significantly higher hatch rate, and nymphs survived better than in all other age groups. There was a strong negative association between the number of eggs placed on the membranes and both hatch rate and survivorship. The ideal number of eggs was less than 200. Preliminary trials with various holidic diets found that one developed for rearing *Myzus persicae* and *Aphis fabae* was comparable, in terms of whitefly nymphal development, to the meridic yeast-extract diet.

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Research & Implementation Area: Section A: Biology, Ecology, and Population Dynamics.

Dates Covered by the Report: 1998

Silverleaf Whitefly Colonization on Upland Cottons and Relationships to Leaf Morphology and Leaf Age

Silverleaf whitefly colonization on Stoneville (ST) 474 and Deltapine (DPL) 5415 cottons in the field was examined in relation to leaf trichome density, leaf age and leaf morphological characteristics as possible factors influencing cultivar host selection. The increased numbers of all silverleaf whitefly life stages on ST 474 in the field appeared to be related to the higher trichome density on abaxial leaf surfaces compared with DPL 5415. In both cultivars, leaves from node #1 below the terminals were smaller and had higher vascular bundle densities and numbers of lysigenous glands than older, larger leaves. Younger leaves also had smaller leaf areole areas, more terminal vein endings per unit leaf area, and shorter distances from abaxial leaf surfaces to minor vein phloem tissues compared with older leaves. These younger leaf morphological characteristics may contribute to the higher silverleaf whitefly densities on younger leaves compared with older leaves. In the laboratory, electronically monitored adult females and visually monitored settled 1st and 4th instar nymphs preferred to probe into secondary and tertiary leaf veins as compared with main and primary leaf veins.

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Research & Implementation Area: Section A: Biology, Ecology, and Population Dynamics.

Dates Covered by the Report: 1996 - 1998

Seasonal Activity of Adult Silverleaf Whiteflies in the Imperial and Palo Verde Valleys, California

Trap studies were conducted in Imperial and Palo Verde Valleys with the objective of determining the seasonal activity pattern and dispersal activity of adult silverleaf whiteflies. Year round trapping in the Imperial and Palo Verde Valleys, California in 1996, 1997 and 1998 showed low adult trap catches from late October to early June and increasing trap catches with increasing seasonal air temperatures and host availability. Trap catches were adversely affected by wind and rain. CC trap catches were significantly correlated to yellow sticky card and suction trap catches. Higher numbers of silverleaf whitefly adults were caught in CC traps directionally oriented to a silverleaf whitefly infested, untreated cotton field as compared with traps oriented toward Bermuda grass fields, farm roads or fallow areas. Abrupt increases in trap catches of 40 to 50 fold more adults for one to two days followed by abrupt decreases in adult catches suggested dispersal activity of adults from other nearby crop sources.

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Research & Implementation Area: Section A: Biology, Ecology, and Population Dynamics.

Dates Covered by the Report: 1999

Evaluation of Leaf-clip Cage and Development of A Single Leaf Plant Technique to Study Photosynthetic Traits of Cotton Under Silverleaf Whitefly Infestation-stress Conditions

Cotton leaf temperatures having leaf clip-cages had leaf temperatures under leaf cage rings 12% higher compared with leaf temperatures outside the leaf clip-cages. This probably occurred because of the pressure of the leaf clip cage rings on leaf tissues and the prevention of transpiration on the parts of leaf blades under the cage rings. Leaf blade temperatures adjacent to the edges of clip-cage rings and inside the cages were 9% and 6% higher, respectively, compared with temperatures outside leaf clip cage rings. A single leaf plant technique, with the stem terminal and all other leaves removed, was developed to evaluate the impact of silverleaf whitefly infestations on cotton leaf physiology. Silverleaf whitefly infestation-stressed plants had reduced photosynthesis and transpiration, and increased leaf temperatures under greenhouse conditions compared with uninfested plants.

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Research & Implementation Area: Section A: Biology, Ecology, and Population Dynamics.

Dates Covered by the Report: 1999

Cotton Leaf Trichomes and Silverleaf Whitefly Density Relationship

Higher trichome density on underleaf surfaces has been attributed to higher silverleaf whitefly density on different cotton cultivars. Studies were conducted to determine whether the positive trichome-insect density relationship holds true among the leaves on main stem leaf nodes. The hairy Stonville (ST) 474 leaves had higher branched trichome densities as well as silverleaf whitefly densities compared with those on smooth NuCOTN (Nu) 33B leaves in a field study at Maricopa, AZ. Mean numbers for trichome and silverleaf whitefly nymphs were 6.9 and 6.0 per 37 mm^2 leaf area for ST 474 compared with 1.7 and 2.9 for Nu 33B, respectively. However, this trichome-insect density relationship did not hold true when leaves from main stem leaf nodes #1, 2, 3, 4, 5, 7, 10 and 15 were compared. The branched trichome densities were 12.3, 8.4, 7.8, 4.9, 7.4, 6.0, 4.6 and 3.5 per 37 mm^2 leaf area on leaves of those leaf nodes for ST 474, but nymph densities were 0.1, 4.1, 13.1, 13.4, 7.1, 7.5, 1.8 and 0.9 per 37 mm^2 leaf area. For Nu 33B the branched trichome densities were 3.5, 2.9, 1.8, 1.9, 1.4, 0.9, 0.9 and 0.2 per 37 mm^2 leaf area and 0.1, 1.8, 4.6, 4.5, 5.6, 3.0, 1.8 and 2.0 per 37 mm^2 leaf area. It appears that factors other than trichome density also influence silverleaf whiteflies colonization. Studies are in progress to examine factors influencing leaf age-silverleaf whitefly density relationship.

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Research & Implementation Area: Section A: Biology, Ecology, and Population Dynamics.

Dates Covered by the Report: 1999

Do Silverleaf Whiteflies Use Leaf Surface Cues for Feeding Sites Selection?

Crawlers have limited mobility and limited time to find feeding sites that assure access to vascular leaf tissues and their survival. We reported earlier that crawlers spend about 80% of their time in contact with vein-associated, elongated epidermal cells and non-glandular branched trichomes located on cotton underleaf surfaces. We also reported that leaf trichomes located in proximity to vascular bundles may provide directional orientation for whiteflies to acceptable feeding sites. Using EPG technique we found lately that adult females probe into secondary and tertiary leaf veins as well as between veins of cotton leaves. It appears that whiteflies may use leaf surface cues for feeding site selection. However, recent descriptions of cotton leaf morphology show that whiteflies can reach phloem tissues from almost any position on the underleaf surface of young leaves and thus may not require the presence of surface cues. Thus, whether whiteflies do use leaf surface cues for feeding site selection remains a question warrant more studies.

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Research & Implementation Area: Section A: Biology, Ecology, and Population Dynamics.

Dates Covered by the Report: 1999

Effect of N Nutrition of Free Amino Acid Levels in Silverleaf Whiteflies

Our objective was to determine how short-term alterations in N nutrition influenced the free amino acid composition of adult silverleaf whiteflies. Insect N nutrition was altered by feeding whiteflies for 2-to-4 days on N-stressed muskmelon plants or on artificial feeders. Free amino acid levels and composition were similar in whiteflies fed on N-sufficient and N-stressed plants. Glutamine was the predominant amino acid in the whitefly bodies, but in all cases we detected a very high level of an amino compound that eluted with the same retention time as proline. In contrast to amino acid levels in the whitefly bodies, the honeydew amino N was markedly reduced for insects feeding on N-stressed plants. This effect was even more pronounced for insects feeding on an artificial diet of 15% sucrose, where amino N was essentially non-detectable after 2 days. As for the insect bodies, glutamine was the predominant amino acid in the honeydew. Proline, however, was detected in very low levels in the honeydew. These results indicate that honeydew composition is quite sensitive to insect N nutrition, thus providing a good indication of N supply to the insect. Although insect amino-N level was not altered by short-term alterations in N nutrition, the rapid effect of N supply on honeydew amino N levels indicates that longer-term exposure to a low-N diet may influence insect N composition and, perhaps, performance.

Investigator's Name(s): Thomas P. Freeman [1], Dennis R. Nelson [2], James S. Buckner [2], C. C. Chu [3], & Thomas J. Henneberry[3].

Affiliation & Location: [1]Electron Microscopy Center, Plant Pathology Department, North Dakota State University, Fargo, ND; [2]USDA--ARS, Bioscience Research Laboratory, Fargo, ND; [3]USDA--ARS, Western Cotton Research Laboratory, Phoenix, AZ.

Research & Implementation Area: Section A: Biology, Ecology and Population Dynamics.

Dates Covered by the Report: 1999

Determination of Stylet Length and the Extent of Stylet Penetration for Silverleaf Whiteflies

Using light and electron microscopy we have determined that the adult *Bemisia argentifolii* Bellows & Perring (Homoptera: Aleyrodidae) stylet lengths are considerably longer than have been previously reported. Adult whitefly stylets range from 100 μm to over 300 μm in length. Stylet penetration was determined by rapidly killing and fixing feeding silverleaf whiteflies in acidified DMP (2,2-dimethoxypropane) and then removing them from the leaves and measuring the stylet extended beyond the distal tip of the labium. The portion of the stylet extended into the leaf ranged from 43 μm to over 150 μm with a mean penetration of 90 μm. Using the same technique to kill and fix nymphs feeding on leaves we found their stylets to also be considerably longer than previously reported. Stylet lengths were found to be shorter in crawlers than in 4th instar nymphs. Crawler stylets measured as long as 113 μm whereas some 4th instar nymphs had stylets over 200 μm long. With stylets of these lengths and the arrangement of minor veins in cotton leaves, both adults and nymphs may be able to reach phloem tissue from almost any point on the abaxial epidermis of the youngest expanding leaves or even leaves located at nodes 7-15 below the apex. Thus, stylet length and phloem depth may not be a determining factor in successful whitefly feeding.

Investigator's Name(s): Thomas P. Freeman [1], Dennis R. Nelson [2], James S. Buckner [2], C. C. Chu [3], & Thomas J. Henneberry[3].

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Research & Implementation Area: Section A: Biology, Ecology and Population Dynamics.

Dates Covered by the Report: 1999

Mechanism and Site of Silverleaf Whitefly Stylet Penetration

The mechanism involved in adult silverleaf whitefly stylet penetration into cotton and hibiscus leaves was determined using light and electron microscopic techniques. The adult silverleaf whitefly can extend, essentially the entire length of its stylet into a leaf. The depth of penetration can range from 100 µm to over 300 µm. The portion of the stylet within the leaf can be determined by examining the position of the head in relationship to the labium.

Utilizing the tilt and rotation capabilities of the scanning electron microscope stage, and by examination of sectioned leaves at both the light and transmission electron microscope level we have determined that the greatest number of penetration sites are directly through epidermal cells rather than through the common wall between epidermal cells or through stomatal pores. Most stylet penetrations that appear to be through the common wall between cells at the light microscope level actually enter directly into the epidermal cell and not through the common anticlinal wall.

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Research & Implementation Area: Section A: Biology, Ecology, and Population Dynamics.

Dates Covered by the Report: January - December 1999

Localization of Whitefly Enzymes

Specific enzymes mediate many of the interactions between the silverleaf whitefly and its host plant. Two whitefly enzymes, alkaline phosphatase and sucrase, have been localized and their potential roles will be discussed. Alkaline phosphatase (ALP) was initially detected in fixed and paraffin-embedded whitefly sections. The most prominent activity is associated with primary salivary glands and could be detected with both colorimetric and fluorescent ALP substrates. Additional activity was detected in accessory salivary glands, salivary ducts, the cibarium and mouth, regions of the oviduct surrounding the terminal oocyte, the colleterial gland, and occasionally within the midgut. Salivary ALP was obtained by collecting and concentrating sucrose diet from whitefly feeder units. Optimal ALP activity was found between pH 10-10.5. Possible functions of whitefly ALP may include a role in nutrient uptake or sclerotization of whitefly structures such as the salivary sheath.

Sucrase plays a key role in the flow of energy from the plant to the insect. Sucrose, the major constituent of cotton sap, is converted to glucose and fructose which are utilized by the whitefly or excreted in honeydew. The enzyme sucrase has been localized in the esophagus and midgut using a precipitating colorimetric substrate. However, the greatest concentration of activity was found in the filter chamber region along the coiled section of the midgut.

Investigator's Name(s): Dale B. Gelman, Michael B. Blackburn, & Jing S. Hu.

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Research & Implementation Area: Section A: Biology, Ecology, and Population Dynamics.

Dates Covered by the Report: 1999

Ecdysteroid Regulation of Molting in 4th Instars of the Greenhouse (*Trialeurodes vaporariorum*) and Silverleaf (*Bemisia argentifolii*) Whiteflies

A system of markers designed to track the development of 4th instar greenhouse whiteflies has been used to track the development of 4th instar silverleaf whiteflies. The system is based on the measurement of body depth and observed changes in the size and color of the developing adult whitefly eye. Stages 0, 1, 2, 3, 4, and 5 have body depths of less than 0.1, 0.1, 0.15, 0.2, 0.25 and 0.27-0.30 mm, respectively. Stages 6, 7, 8, and 9 are characterized by slightly diffuse eye pigmentation, a light red, bright red bipartite and red-black bipartite eye, respectively. Since adult eye development is first observed in stage-6 4th instars, it was hypothesized that molting (i.e., apolysis, the separation of the larval cuticle from the epidermis) occurred shortly before this stage. Histological studies revealed that for the greenhouse whitefly, adult wing and eye development do begin in stage-5 4th instars. (Histological preparations of silverleaf whiteflies are currently being processed.) Metamorphosis is rapid during stage 6. The wing buds become highly convoluted and by stage 7, cuticular spines have been formed. Adult eye formation was also observed to begin in stage-5 4th instars. In stage-6 preparations, the larval cuticle is either missing or is separated from the epidermis.

Since in other insect orders an increase in ecdysteroid levels has been found to be associated with the molt, an Enzyme Immunoassay was used to determine whole body ecdysteroid (molting hormone) titers in staged greenhouse and silverleaf whiteflies. For the greenhouse whitefly, mean whole-body ecdysteroid titers fluctuated between 0.068 and 0.34 pg/whitefly. For the silverleaf whitefly, titers fluctuated between 0.079 and 1.35 pgs/whitefly. Thus, at peak periods (occurred in stage-5 greenhouse and stage 4/5 silverleaf whiteflies), the ecdysteroid titer in 4th instar silverleaf whiteflies is approximately four times greater than the titers in greenhouse whiteflies. Experiments are in progress to identify the ecdysteroids present at the time of the larval-adult molt.

Together, the results described above indicate that pharate adult formation occurs in stage-5 greenhouse whiteflies. It is noteworthy that whole-body ecdysteroid levels of last instar whiteflies are considerably lower than those reported for last instars of other insect orders.

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Research & Implementation Area: Section A: Biology, Ecology and Population Dynamics.

Dates Covered by the Report: 1999-2000

Silverleaf Whitefly Honeydew, Honeydew Sugars and Sticky Cotton

Sticky cotton is a major issue in the textile industry. The problem is widespread and apparent in many parts of the world. A number of contaminants such as crushed seed and seed-coat fragments, pesticides, chemical conditioners used in the cotton gin, oil or grease and immature cotton fiber have been shown to cause sticky cotton. However, the most serious sticky problems have been associated with honeydew contamination as a result of whitefly, *Bemisia* spp., or cotton aphid, *Aphis gossypii* Glover, infestations. Research to identify the sugar components of *Bemisia* honeydew has revealed that, for whiteflies feeding on cotton, two insect-produced sugars, trehalulose and melezitose are the major honeydew components, but a number of other sugars occur in lesser amounts. Trehalulose and melezitose have consistently been shown to be highly correlated to cotton lint stickiness, but as many as 20 individual sugars may occur in whitefly honeydew. Some of the same sugars found in honeydew occur as physiological sugars in the cotton plant (fructose, glucose, and sucrose) and the contributions to lint stickiness of plant physiological and whitefly sugars cannot be separated following extraction from honeydew contaminated lint.

The thermodetector is a readily available device that provides a direct measurement of cotton lint stickiness. It is the internationally accepted method of detecting and quantifying sugar spots on cotton lint. Very simply described, a 2.5 gram sample of cotton lint is spread into a thin mat and layered between two sheets of aluminum foil. The aluminum foil layered lint is heated under pressure. Thereafter, the foil is separated and the number of sticky spots on the foil counted. Studies were conducted with *Bemisia argentifolii* Bellows and Perring honeydew (to analyze the relationship between honeydew and thermodetector counts): 1) 4 and 6% isopropyl alcohol extracts of honeydew from a contaminated cotton bale, 2) honeydew deposited by *B. argentifolii* adults on cotton lint in the laboratory, 3) sprays of commercially-procured individual sugars found in honeydew, and 4) micro-pipette applied drops of honeydew. Increased concentrations of either honeydew extracted from lint or individual honeydew sugars from a commercial source resulted in increased thermodetector counts, as did a mixture of sugars simulating honeydew. Thermodetector counts also increased following sprays with increasing concentrations of 4 and 6% isopropyl alcohol extracts of honeydew. These fractions contain carbohydrates that range from tri- to pentasaccharides. Higher thermodetector counts were correlated with an increasing numbers of drops applied to lint as well as with increasing concentrations of honeydew in the drops.

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Research & Implementation Area: Section A: Biology, Ecology and Population Dynamics.

Dates Covered by the Report: 1999-2000

Silverleaf Whitefly Honeydew Production and Honeydew Sugar Relationships to Sticky Cotton

Bemisia argentifolii Bellows and Perring (= *B. tabaci* (Gennadius) (Strain B) (SPW) pest status is associated with direct feeding damage and reduced crop yields, virus transmission, plant physiological disorders, and contamination of crops with excreted honeydew that serves as a substrate for several fungal species. Fungal growth on foliage can reduce photosynthesis and causes discoloration on cotton lint. The sugar components of honeydew excretions are major factors in the sticky cotton problem. Honeydew deposits on cotton lint adhere to the working surfaces of cotton processing equipment resulting in reduced ginning rates and stoppages of lint processing machinery at the textile mill. The two most abundant sugars found in SPW honeydew are trehalulose and melezitose. These sugars have been shown to increase on cotton lint in the field in conjunction with increasing SPW populations and to be correlated with elevated cotton lint stickiness. Other honeydew sugars cause sticky cotton, but some of these are also plant physiological sugars and cannot be directly identified with SPW when extracted from honeydew contaminated lint. Laboratory studies were conducted to determine the quantity and quality of the major honeydew sugars produced by SPW adults and nymphs. The effects of temperature, light intensity, and SPW adult density on honeydew production were also determined. In the field, we studied the effects of insecticides on SPW populations and on honeydew production of adults and nymphs collected in treated and untreated cotton plots. In the laboratory, adult females lived longer than males, produced more and larger honeydew drops, and, in most cases, larger amounts of the measured honeydew sugars. Both male and female adults produced more honeydew at $26.7 \pm 1°$ C and $32.2 \pm 1°$ C compared with $21.1 \pm 1°$ C. Under our conditions neither light intensity (30 or 450 µmol/second/m^2, respectively), nor adult density affected honeydew production. SPW development from egg hatch to adult emergence averaged 12.2 days at $26.7 \pm 1°$ C. Honeydew production began the first day of nymphal life and peaked on day 3 following emergence. First and second nymphal instars produced more drops than third and fourth nymphal instars. However, honeydew drop size was larger for third and fourth instars compared with first and second instars. The third and fourth instars produced more trehalulose compared with the earlier instars. Adults produced more honeydew than nymphs. The percentage of trehalulose in honeydew was greater for adults as compared to nymphs. Melezitose, as a percentage of all measured sugars, was greater for nymphs as compared with adults.

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Research & Implementation Area: Section A: Biology, Ecology and Population Dynamics.

Dates Covered by the Report: June 1999 - December 1999

Life Table Analysis of *Bemisia tabaci* in Cotton

Bemisia tabaci (Strain B) remains a key pest of cotton and various vegetable crops in the desert southwest. Recent advances in sampling methods and determination of action thresholds have lead to effective management system for this pest in cotton and other crops. However, these systems depend heavily on the efficacy of a few key active ingredients and are not sustainable. Broader-based management systems founded on an understanding of key ecological and biological components of the system are urgently needed in the US and worldwide. Many biotic and abiotic mortality factors impact the population dynamics of *B. tabaci* in agricultural ecosystems, yet we have a poor understanding of the rates of these mortality factors and how they may be involved in overall population regulation. For a multivoltine and multi-crop pest like *B. tabaci* estimating rates of mortality in the field is extremely complex and difficult. There are likely to be large temporal and spatial differences in natural mortality forces within the agroecosystem. The addition of pest management activities provide further sources of mortality that may enhance or disrupt these natural forces. To begin to unravel this complex problem we used a direct observation technique to construct cohort-based life tables of *B. tabaci* on cotton in central Arizona. These studies have identified, quantified, and compared *in situ* sources and rates of mortality of immature whitefly stages in unmanaged (unsprayed) cotton fields and fields subject to different insecticide-based management regimes. Here we present results and analyses based on a total 14 life tables completed in unmanaged cotton from 1997 through 1999.

Cohorts of eggs and settled 1st instar nymphs were established from natural populations in each of 4 replicate plots per generation. Four generations were observed from late June through late September in 1997, six generations were observed from late June through late October in 1998, and 4 generations were observed from late June through late September in 1999. Each cohorts consisted of approximately 50 individuals of each stage in each plot. The location of individuals on leaves was marked with a non-toxic felt-tip pen. The fate of each individual was then tracked by visual observation with a hand lens every 2-3 days. We attempted to estimate mortality due to predation, parasitism, dislodgment, and inviability (eggs). Mortality that could not be placed into one of these categories was cataloged as unknown.

Survival from egg to adulthood ranged from 0-27% and was < 10% in the majority of generations. Predation by sucking predators and dislodgment were major sources of egg and nymphal mortality in most generations. Egg inviability was moderately high during a few generations and an unexplained factor cause high rates of nymphal mortality during 2 generations in 1998 and 1999. Parasitism by aphelinid wasps was consistently low all years. The bulk of mortality occurred in the egg and 4th nymphal stages. Key-factor analyses identified egg inviability and various forces affecting 4th instar nymphs as the best predictors of total generational mortality. Preliminary analyses suggest that most mortality forces act in a density-independent manner, however some weakly density-dependent effects were found. Further analyses showed that relatively little mortality from any source is completely irreplaceable. This suggests that various mortality factors interact and readily replace one another during the 5 developmental stages. The highest rates of irreplaceable mortality were consistently from predation and dislodgment. Many factors contribute to high levels of mortality in unmanaged populations of *B. tabaci* in cotton. This understanding will aid on-going efforts to develop more ecologically-based management strategies for this pest in all affected cropping systems.

Investigator's Name(s): [1]E. T. Natwick,[2]C. G. Summers, [3]C. C. Chu, [2]L. D. Godfrey, [1]K. S. Mayberry, [1]C. E. Bell, & [3]T. J. Henneberry.

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Research & Implementation Area: Section A: Biology, Ecology, and Population Dynamics.

Dates Covered by the Report: 1991 - 1999

Hosts of Silverleaf Whitefly in Imperial and Southern San Joaquin Valleys, California

Plants growing within or around agriculture fields, along fence rows, roadways, waterways, and in urban areas were examined for the presence of silverleaf whiteflies in the Imperial and Southern San Joaquin Valleys, California. A plant was a host when it supported the three life stages (eggs, nymphs and pupal exuvia) of silverleaf whiteflies. When eggs, nymphs and pupal exuvia were not found, the plant species was designated as a non-host species. Leaves from ten plants each species were examined. We have examined 334 plant species since 1991 and found 242 plant species were hosts of silverleaf whiteflies. Numbers of hosts and non-host species, respectively, for each group of plants were: agronomic crops 11 and 7, vegetable crops 47 and 4, ornamental plants, 106 and 72, fruit trees 18 and 5, and weed species 60 and 6. Of the 242 host plant species 149 of them were overwintering hosts. The overwintering hosts included one agronomic crop (alfalfa), 24 vegetable crops, 99 ornamental plant species, 15 fruit tree species, and 20 weed species. This wide host range provides a continuity of year-round plant habitats for *B. argentifolii* reproduction, survival and overwintering.

Investigator's Name(s): Dennis R. Nelson[1], Thomas P. Freeman[2], & James S. Buckner[1].

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Research & Implementation Area: Section A: Biology, Ecology, and Population Dynamics.

Dates Covered by the Report: 1999

Characterization of the External Waxes and Wax Producing Glands of Three Species of Whiteflies

All adult whiteflies studied to date groom and cover themselves, as well as their antennae, with waxy particles, except for their eyes. These particles help to give them a white appearance. Particles shed over an infested leaf surface helps to give it a grayish appearance. Particles are also found sticking to whitefly eggs and on immature stages. These particles are composed of a mixture of long-chain aldehydes and long-chain alcohols in all adult whitefly species examined. One even-numbered chain length of aldehyde and alcohol predominate (about 90%), with the chain length of the dominant component being 34 carbons for *B. argentifolii*, 32 carbons for *T. vaporariorum*, and 30 carbons for *A. dugesii*.

The cuticular surface is also covered by a lipid layer consisting largely of wax esters ranging in chain length, largely even-numbered, from about 32 to 60 carbons. In any given species of adult whitefly, the major wax esters consist of compounds with chain lengths of 40, 42, 44 or 46 carbons. The cuticular surface lipids contain very small amounts of hydrocarbons. No wax esters or hydrocarbons are associated with the waxy particles.

In order to produce the copious amounts of waxy particles, the majority of the abdominal surface is covered with wax plates. These wax plates are composed of many microtrichia which extrude the waxy material. The waxy material is in turn broken off by the tibia to form the particles.

The number of microtrichia were determined per square micrometer. There were 0.49/ m^2 in the silverleaf whitefly, *Bemisia argentifolii*, 0.47/ m^2 in the greenhouse whitefly, *Trialeurodes vaporariorum*, and 0.43/ m^2 in the giant whitefly, *Aleurodicus dugesii*.

The microtrichia are in the shape of a 'T' in which all arms appear to be the same length. The length of an arm was 0.7 for *B. argentifolii*, 0.8 for *T. vaporariorum*, and 1.0 for *A. dugesii*.

The length and width of the waxy particles were: 5.0 by 0.8 for *B. argentifolii*, 4.7 by 0.9 for *T. vaporariorum*, and 11.1 by 1.3 for *A. dugesii*. The particles from *B. argentifolii* and *T. vaporariorum* are semicircular and form shapes resembling the letter 'C' or a 'horse collar'. These shapes are effective in enabling the particles to stick to the hairs of the whiteflies. However, the particles from *A. dugesii* do not curl, they remain as straight fragments on the cuticular surface and do not accumulate to the extent observed for the semicircular particles of the other whiteflies.

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Research & Implementation Area: Section A: Biology, Ecology And Population Dynamics.

Dates Covered by the Report: January - December 1999

Biology, Ecology and Morphometrics of *Bemisia Tabaci* Genn. on Cassava, Sweet Potato, Brinjal, Cotton and Tobacco

Investigation carried out on comparative biology of *Bemisia tabaci* in five major crops are covered in the paper. Developmental duration, fecundity, longevity and sex-ratio of *B. tabaci* was studied on cassava, sweet potato and cotton, under natural conditions (Tem. 29.76 degree celsius, RH 79.29%). Total life cycle of the whitefly was 23.5, 19.5 and 20.0 days on cassava, sweet potato and cotton respectively. Mean total fecundity on cassava, sweet potato and cotton was 45.0, 41.67 and 41.3 respectively. Female longevity was greater on cassava (17.8 days) than on sweet potato (16.33 days) and cotton (13 days). Sex ratio (Male: Female) of *B. tabaci* was 1:1.8 on cassava; 1:1.59 on sweet potato and 1:1.2 on cotton.

It was observed that the cassava whitefly was found to breed only on cassava, eggplant and tobacco, while sweet potato whitefly was breeding only on sweet potato, eggplant, tobacco and cotton. Total life cycle of cassava whitefly on tobacco and egg plant ranged from 16.0-18.0 and 15.3-17.3 respectively; sweet potato whitefly on cotton, egg plant and tobacco ranged from 17.0-23.0, 18.0-23.0, 17.0-21.0 days respectively. Morphometric studies of fourth instar (pupae) on all five plants showed clear sexual dimorphism. The implications of these findings are very significant in further investigation of Biotype identification, through crossing/breeding and isozyme studies.

Investigator's Name(s): C. H. Pickett & D. Overholt[1].

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Research and Implementation Area: Section A: Biology, Ecology, and Population Dynamics.

Dates Covered by the Report: August 1997 - November 1998

Survivorship of Silverleaf Whitefly Overwintering in Citrus in the San Joaquin Valley

The survivorship of silverleaf whitefly *Bemisia argentifolii* has been monitored in citrus throughout the year as part of an effort to establish new, exotic parasites of this pest. Four study sites have been used, one each in Fresno, Tulare, and two in Kern Counties. Sites consisted of citrus and cotton acreage managed by the same owner. Cotton is grown directly adjacent to the citrus, and growers have had a history of silverleaf whitefly problems. The whitefly population on citrus leaves was monitored by counting, depending on time of year, once every 1 to 4 weeks. Leaves were removed from trees, shipped to our laboratory, and examined for the number of parasitized pupae, whitefly eggs, early instar nymphs, and late instar nymphs using a dissecting microscope.

I summarized whitefly density counts using a multicohort stage frequency analysis method to measure the survivorship of silverleaf whitefly (Manly, B. 1990. Stage-Structured Populations, Sampling, Analysis and Simulation). We wanted to measure the number of eggs laid on citrus leaves in fall that successfully developed to adults the following spring. Few whitefly reproduce in citrus during summer months. Large numbers of adults, however, migrate into orchards shortly or during cotton defoliation, i.e., September - November. Two estimates were used to measure the likelihood of eggs maturing to adults over this period of time when whiteflies were continuously present in the orchards: survivorship from egg to adult, and from egg to late nymph, the former being a far more conservative measurement (successful adult maturation was measured by the presence of an exit hole in the late stage exuviae, which can fall off within two weeks of adult eclosion, i.e. some were likely missing). The actual value is probably somewhere in between. On average from 1997 to 1998, 0.073% to 3.73% of eggs survived to adults. The following winter fewer whiteflies survived, 0.036% to 0.38%, an entire order of magnitude less. Summer – fall, 1998 was cooler than the former, which may explain part of the drop in survivorship. The peak in egg production came almost two months later in 1998 (November vs. September), increasing the exposure of eggs to lower temperatures. Also, the actual number of eggs oviposited was about half in 1998 than in 1997: 12.5 vs. 7.6 (not including the new site in Kern County). Another trend is the drop in egg survivorship as one moves from the southern end of the San Joaquin Valley to the central region. This was not true for other instars suggesting egg survivorship is more sensitive to lower temperatures than nymphal stages.

The delay in cotton maturity, as a result of the cool spring, undoubtedly played a role in forestalling the migration of whiteflies from this preferred host plant. Parasitism of silverleaf whitefly on citrus was always quite low, even in the second year of releases, rarely exceeding 10%, despite the massive releases of parasites into these trees (see Pickett et al., this volume). Survivorship data shows that anywhere from 49% to 100% late instar whiteflies die before maturing to adults. Most likely many young parasites never fully develop because they die within these hosts. Under optimal conditions, i.e. inside a heated greenhouse, we have found up to 72% of nymphs dying in the absence of any predation or parasitism. Citrus appears to be a poor host for silverleaf whitefly.

Investigator's Name(s): Michael E. Salvucci & Steven J. Crafts-Brandner.

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Research & Implementation Area: Section A: Biology, Ecology and Population Dynamics.

Dates Covered by the Report: January 1999 - December 1999

Effects of Temperature and Dietary Sucrose Concentration on Respiration in the Silverleaf Whitefly, *Bemisia argentifolii*

A system was developed to measure homopteran respiration during feeding. Insects were placed in a flow-through respiration chamber that was specifically designed to provide access to an artificial diet. The respiration chamber was connected to a commercial infra-red gas analyzing system that continually monitored and recorded respiratory CO_2 evolution during feeding. Using this system, respiration rates of 240 and 251 µmol CO_2 h^{-1} g^{-1} were determined for whiteflies and cotton aphids, respectively, at 30°C on diets containing 15% sucrose. Whitefly respiration increased with temperature over the range of 25 to 46°C with a Q_{10} of about 2.12 on diets containing 15% sucrose. Respiration rates were similar throughout this temperature range on diets containing 10, 15 and 20% sucrose, but were considerably lower at all temperatures on diets containing 2.5% sucrose and at temperatures greater than 35°C on diets containing 5% sucrose. Respiration rates decreased following the addition of sodium azide to the diet or upon extended exposure to 47°C. The rate at which respiration decreased at 47°C was inversely related to the concentration of sucrose in the diet over the range of sucrose concentrations from 2.5 to 15% sucrose. The results indicate that whiteflies require a sucrose concentration of between 5 and 10% (i.e., 0.15 and 0.3 M) for maximum basal metabolism. Higher concentrations of sucrose in the diet delayed high temperature mortality, possibly a reflection of the high sucrose requirement for sorbitol synthesis in these insects.

Investigator's Name(s): Alvin M. Simmons [1], Gloria S. McCutcheon[2], Richard J. Dufault[2], Richard L. Hassell[2], & James W. Rushing[2].

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Research and Implementation Area: Section A: Biology, Ecology, and Population Dynamics.

Dates Covered by the Report: 1998-1999.

Bemisia and Associated Parasitoids on Species of Medicinal Herbal Plants

Most whitefly related research has focused on row, horticultural, and ornamental crops. In addition, weed and some other species have been examined as whitefly hosts because of associated plant pathogens and other aspects of whitefly ecology. Consumers have expressed much interest in medicinal herbals over the past decade, and industry has been trying to respond to the demand. A multi-study research project was recently initiated on the production potential of selected medicinal herbal plant species as new crops suitable for cultivation in South Carolina. One phase of the research examined the vulnerability of 5 medicinal herbal species to *Bemisia argentifolii* Bellows and Perring. In an experimental production field, natural populations of adult and immature *B. argentifolii* infested the 5 perennial species of medicinal herbal plants (feverfew, *Tanacetum parthenium* (L.) Schultz-Bipontinus; St. John's wort, *Hypericum perforatum* L.; purple coneflower, *Echinacea pallida* (Nuttall) Nuttall and *E. purpurea* (L.) Moench; and common valerian, *Valeriana officinalis* L.). Whiteflies have not been previously reported in the literature on these plant species. Capture of adult whiteflies on yellow sticky cards agreed with the relative density of immatures among the plant species. The density of whiteflies was greater on some of the species, such as *E. purpurea*, than on others. Similarly, adult capture on sticky cards was high in plots of *E. purpurea* compared with plots of the other 4 species, and adult counts were elevated in the highest (440 kg N/ha) of 3 fertility rates in *E. purpurea*. Likewise, laboratory choice and no-choice tests agreed with the observation of a higher population of *B. argentifolii* on *E. purpurea* compared with the other 4 plant species. The whitefly completed development on all 5 plant species, and whitefly associated parasitoids emerged from field leaf samples of each plant species. The impact of the whitefly was not determined, but the data indicate potential problems from this pest. While all 5 species in this study supported feeding and development by *Bemisia*, the commercial use of these plants dictates restrictions on the use of traditional insecticides.

Research Summary

Section A: Biology, Ecology, and Population Dynamics

Compiled by Mike Salvucci & Tom Perring

Research continued in the following five general areas of study encompassed by this section: ecology and population dynamics, evaluation of food and fiber quality, basic biological processes, feeding behavior, and aspects related to nutrition and nutritional biochemistry. Progress was made in 6 of the 10 research approach areas that are included under section A.

Ecology and Population Dynamics.
A life table analysis of Bemisia in cotton was presented as a keynote talk given by Naranjo and Ellsworth in Section F. The results and analyses of 14 lifetables completed in unmanaged cotton from 1997 through 1999 showed that survival of whiteflies from egg to adulthood ranged from 0-27% and was <10% for the majority of generations. The study revealed that predation by sucking, dislodgment of eggs and nymphs, and egg inviability were major sources of mortality. In contrast, parasitism was consistently a low source of mortality. Further analyses showed that the mortality factors interacted and replaced one another, indicating that many factors contribute to high levels of mortality in unmanaged cotton.

Also included under the general area of ecology and population dynamics were presentations on whitefly overwintering, seasonal and host distribution, and the occurrence of whiteflies on medicinal plants. The research on overwintering examined the occurrence and reproduction of whiteflies in citrus in the San Joaquin. Using multicohort stage frequency analysis to measure survivorship, Pickett and Overholt showed that, even though large numbers of adult whiteflies migrated into orchards during cotton defoliation, the likelihood of eggs maturing to adults was very low, 0.073 to 3.73% in 1997-1998 and 0.036 to 0.36% 1998-1999. Research by Chu et al. on the seasonal activity of adult whiteflies in the Imperial and Palo Verde Valleys of California found that low numbers of adults were caught in traps from late October to early June in 1996, 1997 and 1998. The study also recorded abrupt increases in trap catches, indicative of dispersal activity. Research on whitefly hosts in the Imperial and San Joaquin Valleys showed that of the 334 plant species examined, 242 were hosts for the whitefly. The wide host range included many that provided an overwintering habitat including alfalfa, as well as 24 vegetable crops, 99 ornamental plants, 15 fruit trees and 20 weed species. Whitefly distribution was also extended to five perennial species of medicinal plants in South Carolina. Whiteflies completed development on all five species of medicinal plants, indicating that all five plants were vulnerable to attack by whiteflies.

Evaluation of Food and Fiber Quality
Two reports from Henneberry et al. described research on the problem of contamination of cotton fiber by whitefly honeydew (sticky cotton). In one of the reports, the group examined factors the affect the quantity and quality of honeydew. The results showed that adult whiteflies produced more honeydew than nymphs and that adult females produced more honeydew than adult males. More honeydew was produced at higher temperatures, but light intensity no affect on honeydew production. In the second study, this group evaluated measurements of cotton stickiness made with a thermodetector. They showed that higher thermodetector counts correlated with higher amounts of honeydew on the cotton lint.

Basic Biological Processes
Several reports dealt with biological processes related to whitefly nutrition and these are discussed below. In addition, two reports were presented on basic biological processes unrelated to nutrition. One report communicated information about the external waxes and wax producing glands of 3 whitefly species. Characterization of the surface of the whiteflies showed it consists largely of wax esters ranging in chain length from 32 to 60 carbons. Electron microscopy of the abdominal surface showed that the surface is covered with wax plates composed of microtrichia that extrude the waxy material. The length and width of the waxy particles were measured for the 3 whitefly species.

The other report under this sub-category was a study of ecdysteroid regulation in the 4th instar stage of two whitefly species. Gelman and colleagues have made considerable progress in this area, devising a system of 9 markers for tracking development of 4th instar development. This group has been able to measure ecdysteroid titers in 4th instar larvae using ELISA, and have found that the levels peak at stage 4/5.

Feeding behavior
Several reports were presented in this category from the USDA groups at Phoenix and Fargo and their University of California collaborators. These groups reported a number of interesting finds on the relationship of whitefly feeding and stylet penetration to leaf morphology. In one of the studies, the higher whitefly densities on younger leaves were attributed to higher densities of vascular bundles and lysigenous glands in younger compared with older leaves. Measurements of trichome density were made on a hairy and a smooth cotton variety but a trichome to insect density relationship was not established, indicating that factors other than trichome density influence whitefly colonization.

In three of the studies, measurements were made of stylet length and penetration. The results significantly advanced our understanding of whitefly feeding behavior by showing that whitefly stylets can extend from 100 to 300

µm, a length sufficient to reach the phloem tissue from any point on the abaxial surface. In addition, these studies showed that stylet penetration was generally through the epidermal cells of the leaf rather than between epidermal walls or through stomatal pores.

Nutrition and Nutritional Biochemistry

The reports in this sub-category dealt with carbon and nitrogen nutrition, as well assessment of artificial diets for rearing whiteflies. In one report, two enzymes involved in nutrition were localized in the whitefly. One of these enzymes, sucrase, is a key enzyme of carbohydrate metabolism in whiteflies. The finding that this enzyme was localized to a region of the filter chamber has important implications for understanding carbohydrate metabolism in whiteflies. Another study dealing with carbohydrate metabolism involved measurements of whitefly respiration at various temperatures during feeding. The results established that whiteflies have very high metabolic rates and that they require between 5 and 10% sucrose in the diet to support these rates.

One of the reports in this sub-category examined nitrogen nutrition in adult whiteflies. Analyses showed that glutamine and proline were the major amino acids in the bodies of whiteflies. The study also found that honeydew was very sensitive to N nutrition, a possible indication that long-term exposure to a low-N diet may influence insect performance. Finally, Blackmer et al. presented a report describing research that evaluated various artificial diets for rearing whiteflies. Using a system consisting of a teflon membrane in a polycarbonate feeding chamber, survivorship and hatch rates were measured on various diets and optimal rearing conditions were established.

Table A. Biology, Ecology, and Population Dynamics.

Research Approaches	Year 1 Goals Statement	Progress Achieved Yes	No	Significance
Determine life cycle vulnerabilities (life tables)[a], population development and natural mortality factors, natural enemies on major crops, urban plantings, weeds and predict overwintering potential.	Whitefly and natural enemy sampling in cultivated crops, urban planting and weed hosts.	X		Partial life table analyses have been completed for *B. argentifolii* on cotton in Arizona. Natural forces, including predation and dislodgment are major mortality factors; parasitism was a minor source of mortality. Survivorship from egg to adult ranged from 0-8.5% over 4 generations in sprayed and unsprayed fields. Studies on wild host crops in Israel indicate that parasitoids may contribute to low levels of whitefly on lantana. Whitefly and natural enemy populations were monitored in cropping systems in the Imperial and San Joaquin Valleys of California, Maricopa, Arizona and the Rio Grande Valley of Texas. The spread of *B. argentifolii* is being documented in Brazil. Life table studies provide valuable quantitative information on sources of whitefly mortality; surveys define the temporal and spatial dynamics of pest and natural enemy populations. This information is critical in developing and refining more biologically-based management systems.
Develop sampling methodology, action and[b,c] economic thresholds for all major crops. Sampling methods and thresholds modified in light of natural enemy levels and existing management strategies.	Initiate whitefly to identify spatial and temporal distributions in major cultivated crops.	X		Relationships between whitefly density and the occurrence of tomato irregular-ripening as well as preliminary sampling plans for whitefly on tomato have been developed. Evaluations of a reusable trap for surveying adult whiteflies in various crops are continuing. Studies of the effects of various insecticides on whitefly natural enemies are ongoing. Sampling plans and action thresholds are still needed for a number of affected crops.

Table A. Biology, Ecology, and Population Dynamics. (Continued)

Research Approaches	Year 1 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Develop population models to describe and predict whitefly population growth and spatial and temporal distribution. Develop simple day-degree sub-models for estimating phenology and temporal patterns of whitefly, natural enemies and host crops.	Summarize whitefly biology, ecology and plant phenology to identify whitefly host plant interfaces.	X		Development of large-scale temporal and spatial models and temperature-dependent, site-specific population dynamics models continues. Such models have the potential to encapsulate our current knowledge and provide a framework for developing more efficient management systems. However, considerable biological and ecological detail, as well as information on various aspects of pest management is available and needs to be integrated into these models to make them most useful as exploratory tools.
Develop sampling methods for quality of cotton lint, vegetables and other commodities.	Initiate sampling of seed cotton in the field during the season, at harvest, after picking, moduling and ginning.	X		Research has characterized the temporal distribution of honeydew deposition by *B. argentifolii* in cotton, improved our understanding of the relationship between lint stickiness and whitefly abundance and compared the production of trehalulose and melezitose between nymphs and adults. Studies reveal that cotton lint stickiness is randomly distributed in cotton fields. Preliminary sampling plans have been developed for estimating pre-harvest cotton lint stickiness. Stickiness constitutes one of the most important problems currently facing the cotton industry.
Quantify whitefly and natural enemy dispersals and contribution to population dynamics.	Review and analyze existing knowledge of whitefly dispersal.	X		Studies have characterized the aerial distribution of whiteflies dispersing from cantaloupe fields and have examined the trade-offs between oogenesis and flight activity. Studies on whitefly parasitoid dispersal are ongoing. Understanding and predicting the timing and extent of the movement of whiteflies and their natural enemies is an important component in developing areawide management systems.

Table A. Biology, Ecology, and Population Dynamics. (Continued)

Research Approaches	Year 1 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Define mating behavior, reproductive isolation, species, biotypes.	Initiate studies on mating, oviposition and other behavior.	X		Surveys worldwide continue to document the spread of *B. argentifolii*. Electorphoretic analyses demonstrate the presence and extent of this pest in throughout Australia and Brazil. *B. argentifolii* appears to be displacing *B. tabaci* Biotype A in Brazil and is having a large impact on agricultural production through direct feeding and geminivirus transmission. Reports of heterozygotes between *B. argentifolii* and the extant Australian type *of B. tabaci* corroborates previous laboratory and highlight the taxonomic challenges within the *Bemisia* species complex.
Validate *Bemisia* taxa morphology, genetic, biochemical, and biology characteristics.	Continue examination of *Bemisia* sp. for distinct morphological character differences.	X		Comparative morphological analyses have been completed on *Bemisia* pupae from around the world. Several of these characters are highly variable among populations suggesting that pupal morphology should not represent the sole criteria for classifying individuals within the *Bemisia* species complex.
Define role of endosymbionts in metabolism, host adaptation, nutrition and survival.	Identify endosymbionts in whitefly.	X		The effects of antibiotics on the biology of *B. argentifolii* have been examined. Several antibiotics that interfere with bacterial protein synthesis affected growth and development of immatures, but none affected oviposition rates or sex ratio. Results have important implications for the use of antibiotics to disrupt the function of whitefly endosymbionts and other associated microbes as potential control methods.
Characterize nutrient uptake and metabolism	Determine the process of uptake and metabolism of carbohydrates, amino acids and other nutrients.	X		High levels of a polyol, sorbitol, were associated with elevated ambient temperatures. Sorbitol may function as a thermoprotectant in whiteflies that enables them to thrive in desert environments. The pathway of sorbitol synthesis and degradation in *B. argentifolii* is unique and may offer and avenue to develop transgenic plants which could disrupt sorbitol synthesis and compromise the whiteflies ability to deal with heat stress.

Table A. Biology, Ecology, and Population Dynamics. (Continued)

Research Approaches	Year 1 Goals Statement	Progress Achieved Yes	No	Significance
Develop whitefly artificial diets and natural enemy mass-rearing.	Identify whitefly nutritional components in plant tissue.	X		An artificial diet and feeding system for rearing immatures of *B. argentifolii* has been developed. Rates of development of individual instars were comparable to those estimated on various host plants. The feeding system has proven to be a useful bioassays for examining diet components and for studies of primary metabolism based on defined diets, and has the potential to provide a means of mass rearing whitefly parasitoids.

[a] Natural enemy research complements from Section D, see Table D.
[b] Action and economic thresholds also apply in Section C, see Table C.
[c] Sampling technology applicable to all other sections, see Tables B to F.

Table A. Biology, Ecology, and Population Dynamics.

Research Approaches	Year 2 Goals Statement	Progress Achieved Yes	No	Significance
Determine life cycle vulnerabilities (life tables)[a], population development and natural mortality factors, natural enemies on major crops, urban plantings, weeds and predict overwintering potential.	Determine potential of intercrop weed host & urban planting, movement of whiteflies and natural enemies.	X		Life table studies continued to characterize and quantify mortality factors for immatures of *B. argentifolii* on cotton. Predation and dislodgment accounted for much of the mortality in untreated fields and survivorship from egg to adult ranged from 0-18.2% over 6 generations. Several perennial plants species show potential to serve as refugia for exotic and native parasitoids. Life history and reproductive potential has been studied on various crop and weed hosts in the US and Italy. Whitefly population dynamics and virus incidence has been examined in cropping systems in Costa Rica, India and Guadaloupe. These ecological and biological studies form the foundation of effective pest management strategies.
Develop sampling methodology, action and[b,c] economic thresholds for all major crops. Sampling methods and thresholds modified in light of natural enemy levels and existing management strategies.	Analysis and identification of needed additional sampling research to develop appropriate sampling protocol.	X		A multistate study determined action thresholds for cotton in Arizona and California. Evaluations of a reusable trap for surveying adult whiteflies in various crops are continuing. Studies of the effects of various insecticides on whitefly natural enemies are ongoing. Sampling plans and action thresholds are still needed for a number of affected crops.
Develop population models to describe and predict whitefly population growth and spatial and temporal distribution. Develop simple day-degree sub-models for estimating phenology and temporal patterns of whitefly, natural enemies and host crops.	Begin model development to include all biological and plant phenology data in simulation development.	X		The first version of a temperature-dependent, site-specific population dynamics model of *B. argentifolii* in cotton and cantaloupe was completed. Additional refinements, enhancements and field validation are needed to improve the utility of the model for predicting whitefly population dynamics under various management regimes and environmental conditions. In general, considerable biological and ecological data are available and need to be integrated into these models to make them most useful as exploratory tools.

Table A. Biology, Ecology, and Population Dynamics. (Continued)

Research Approaches	Year 2 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Develop sampling methods for quality of cotton lint, vegetables and other commodities.	Based on year 1 results, expand and repeat sampling protocols as described.	X		Comparative evaluations of manual and high speed cotton stickiness thermodetector revealed differences in performance that have important implications for the development of measurement scales for stickiness and the number of samples that would need to be collected for the precise estimation of stickiness. Research on quality-related problems in other affected crops is needed.
Quantify whitefly and natural enemy dispersals and contribution to population dynamics.	Validate times of whitefly dispersal, environmental factors and identify modifying factors.	X		Studies on whitefly and parasitoid dispersal are ongoing in the desert southwest. Understanding and predicting the timing and extent of the movement of whiteflies and their natural enemies is an important component in developing areawide management systems.
Define mating behavior, reproductive isolation, species, biotypes.	Define interspecies interbiotype mating interactions.	X		Research continues on the role of reproductive isolation in the formation of species and biotypes, using insects from around the globe. There has been little detailed study of mating behavior *per se*, and its relevance for mating incompatability.
Validate *Bemisia* taxa morphology, genetic, biochemical, and biology characteristics.	Develop genetic molecular level and acceptable species level separation.	X		Molecular characterization of the global whitefly complex is ongoing to clarify the taxonomic relationships between *Bemisia* whitefly populations. The whitefly karyotype has been determined and is an important development in our understanding of whitefly reproduction.
Define role of endosymbionts in metabolism, host adaptation, nutrition and survival.	Determine role of endosymbionts in whitefly biological functioning.	X		The discovery of *Wolbachia* endosymbiotic bacteria in whiteflies is a new development that has significant implications for development of control strategies targeting the reproductive biology of whiteflies.

Table A. Biology, Ecology, and Population Dynamics. (Continued)

Research Approaches	Year 2 Goals Statement	Progress Achieved Yes	No	Significance
Characterize nutrient uptake and metabolism	Determine the biochemical pathways for metabolism of compounds essential for whitefly development.	X		Fndamental questions about the nutritional physiology of whiteflies are being answered with the aid of artificial diets. Biochemical pathways for carbohydrate metabolism and polyol synthesis have been determined. Metabolism of plant toxins is being studied to assesss the ability of *Bemisia* to detoxify plant deterrent compounds. The role of nitrogen fertilization in whitefly-cotton interactions was determined in field trials.
Develop whitefly artificial diets and natural enemy mass-rearing.	Develop whitefly artificial feeding systems.	X		Development of an artificial feeder for whiteflies that will support development from egg to adults has been successful, and improvements continue to increase the proportion of *Bemisia* adults produced. This system has been tested for its effectiveness at supporting parasitoid wasp development, and adult *Encarsia* have been successfully produced in this system. Further research is needed to optimize the system for both whitefly and parasitoid development.

[a] Natural enemy research complements from Section D, see Table D.
[b] Action and economic thresholds also apply in Section C, see Table C.
[c] Sampling technology applicable to all other sections, see Tables B to F.

Table A. Biology, Ecology, and Population Dynamics.

Research Approaches	Year 3 Goals Statement	Progress Achieved Yes	No	Significance
Determine life cycle vulnerabilities (life tables)[a], population development and natural mortality factors, natural enemies on major crops, urban plantings, weeds and predict overwintering potential.	Identify potential low population manipulation on vital host links for survival	Y		Low survivorship was documented both on cotton during peak season and on citrus during overwintering. Mortality factors were identified and shown to have overlapping influence. Seasonal distribution on various host species was determined.
Develop sampling methodology, action and[b,c] economic thresholds for all major crops. Sampling methods and thresholds modified in light of natural enemy levels and existing management strategies.	Validate and refine sampling methods.		X	
Develop population models to describe and predict whitefly population growth and spatial and temporal distribution. Develop simple day-degree sub-models for estimating phenology and temporal patterns of whitefly, natural enemies and host crops.	Provide model simulation of whitefly populations and multiple cropping systems.		X	
Develop sampling methods for quality of cotton lint, vegetables and other commodities.	Develop sampling protocol for field and harvest and processing sampling and determine interrelationships.	X		Correlations established between thermodetector measurements of cotton stickiness and amounts of honeydew on the fiber.
Quantify whitefly and natural enemy dispersals and contribution to population dynamics.	Determine proportion of whitefly population that are migratory and their reproductive potential.	X		Trapping studies showed low dispersal for October to early June and evidence for sudden dispersal activity
Define mating behavior, reproductive isolation, species, biotypes.	Define factors involved in mating, cues, feedback mechanisms, etc.		X	
Validate *Bemisia* taxa morphology, genetic, biochemical, and biology characteristics.	Discuss results, plan additional research, arrive at a consensus decision.	X		Difference in ecdysteroid titers and waxy particle length, width and morphology documented between *Bemisia* and other whiteflies.

Table A. Biology, Ecology, and Population Dynamics. (Continued)

Research Approaches	Year 3 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Define role of endosymbionts in metabolism, host adaptation, nutrition and survival.	Determine potential for manipulating, interfering with or inhibiting endosymbiont function.		X	
Characterize nutrient uptake and metabolism	Determine the physical and biochemical processes involved in uptake of carbohydrates, amino acids and other essential nutrients.	X		Length of stylet determined and correlated with vascular bundle depth. Basic metabolic rate and minimum carbohydrate content to support this rate were determined. Preliminary analysis of amino acid metabolism was conducted.
Develop whitefly artificial diets and natural enemy mass-rearing.	Conduct addition, deletion studies to identify essential nutritional needs.	X		Optimal conditions of pH and egg load were established. Hatching and survivorship was evaluated on various artificial diets.
****Pursue specific genetic and biological basis for variability in whitefly biotypes, strains, and species; determine impact of different genetypes/phenotypes on whitefly-mediated transmission and on the epidemiology of virus diseases.**	Continue with work from previous years. Study impact of biotypes, strains, and species differences in the disease spread, crop damage, and specific control measures to reduce whitefly vector populations. Linkages with biological and chemical control sections.		X	This research approach transferred to section A

[a] Natural enemy research complements from Section D, see Table D.
[b] Action and economic thresholds also apply in Section C, see Table C.
[c] Sampling technology applicable to all other sections, see Tables B to F.
** Transferred from Table B 3/31/2000

Reports of Research Progress

Section B: Viruses, Epidemiology, and Virus-Vector Interactions

Co-Chairs: Bob Gilbertson and Robin Huettel

Investigator's Name(s): Robert L. Gilbertson

Affiliation & Location: Department of Plant Pathology, University of California-Davis

Research & Implementation Area: Section B: Viruses, Epidemiology, & Virus-Vector Interactions.

Dates Covered by the Report: December 1998 – December 1999

A New Bipartite Geminivirus (Begomovirus) Causing Cucurbit Leaf Curl and Crumpling Symptoms in the Imperial Valley of California

In the fall of 1998, volunteer watermelon plants, growing in a commercial honeydew melon field in the Imperial Valley of California, showed symptoms of leaf crumpling and yellowing that were suggestive of a geminivirus infection. Geminivirus infection in watermelon leaves showing these symptoms was established by squash blot hybridization analysis with a general probe for Western Hemisphere whitefly-transmitted geminiviruses (Family Geminiviridae, Genus Begomovirus) and by PCR analysis with degenerate PCR primers for the DNA-A and DNA-B components of bipartite begomoviruses. DNA-A (~1.2 kb) and DNA-B (~1.6 kb) fragments were amplified from DNA extracts prepared from symptomatic leaves and were cloned and sequenced. The DNA-A and DNA-B fragments had a nearly identical (99.5%) common region sequences, indicating they were from the same geminivirus. Database searches conducted with these sequences revealed no high degree of sequence identity (i.e., >90%) with other begomoviruses, including *Squash leaf curl virus* (SqLCV) from Southern California. Depending on the sequence used for comparsion, the highest sequence identities were with *Tomato severe leaf curl virus* from Guatemala, SqLCV, *Squash yellow mottle virus* from Costa Rica, and *Bean calico mosaic virus* from Mexico. Evidence that this geminivirus was responsible (at least in part) for the disease symptoms in the watermelon volunteers came from experiments in which a DNA extract prepared from watermelon leaves with the crumpling and yellowing symptoms were inoculated into watermelon seedling by particle bombardment. Inoculated seedling developed leaf crumpling and distortion symptoms and geminivirus infection in these seedlings was demonstrated by PCR analysis. Watermelon seedlings bombarded with gold particles alone did not develop symptoms. These results establish that the watermelon volunteers were infected by a new bipartite begomovirus. Surveys of spring melons in the Imperial Valley indicated that leaf crumpling and/or yellowing symptoms were not common. However, the new begomovirus was detected from cantaloupe and watermelon leaves with crumpling and yellowing symptoms that were collected on July 2 and August 17, 1999. A survey of fall melons conducted September 23-24, 1999, revealed widespread symptoms of leaf curl and crumpling on new growth of muskmelon plants in all seven commercial fields examined (estimated incidence: 25-50%). No such symptoms were observed on honeydew melon plants. These plants were determined to be infected with the new begomovirus based on sequence analysis of PCR-amplified DNA-A fragments. These results suggest that a new cucurbit-infecting begomovirus has appeared in the Imperial Valley of California and that it has rapidly be spread through the area, presumably by whiteflies. Based on it's most diagnostic symptoms and capacity to infect a range of cucurbits, the name *Cucurbit leaf crumple virus* (CuLCrV) is proposed. It will be important to carefully monitor for the incidence of CuLCrV to and to assess the capacity of CuLCrV to cause economic losses in desert melon production.

Investigator's Name(s): Moshe Lapidot, Rachel Ben-Joseph, Michael Friedmann[1], Meir Pilowsky[1], & Shlomo Cohen.

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Research & Implementation Area: Section B: Viruses, Epidemiology, and Virus-Vector Interactions.

Dates Covered by the Report: 1999

The Effect of TYLCV-Resistant Tomato Plants on Virus Epidemiology

Tomato yellow leaf curl virus (TYLCV), transmitted by the tobacco whitefly (*Bemisia tabaci* Genn.), can be devastating to tomato (*Lycopersicon esculentum* L.) crops in tropical and subtropical regions, causing up to 100% crop loss. Control measures in infected regions are based on limitation of the vector population, which usually requires heavy pesticide use and physical barriers such as 50 mesh nets. Since control of the viral vector is difficult or nearly impossible, the development of resistant cultivars is the best option for control of TYLCV. However, all the resistant commercial cultivars tested at the Volcani Center, when infected with TYLCV, developed different levels of disease symptoms (1). Recently, we reported the development of a novel source of resistance to TYLCV, breeding line TY172, which is a symptomless carrier of TYLCV (2). Line TY172, whether infected in the greenhouse with virulifelous whiteflies, or when grown in the field under natural infection, showed no symptoms of the disease. Viral DNA was detected in infected TY172 plants, albeit at much lower levels than a susceptible infected control. In addition, grafting experiments utilizing infected susceptible scions grafted onto TY172 stocks, showed that even when exposed continuously to very high levels of virus, line TY172 did not develop disease symptoms, nor did it accumulate high levels of the virus.

In the present study, we tested the effect TYLCV-resistant tomato plants have on virus epidemiology. In order to understand the effect resistant tomato plants have upon TYLCV transmission by whiteflies (WFs), we have chosen three different TYLCV-resistant plants, cv. Fiona, cv. 8484, TY172, and as a control a TYLCV-susceptible tomato line, L27. Ten plants from each line or cv. were inoculated with TYLCV and served as source plants for TYLCV acquisition by WFs. Following a 48-hr acquisition access period, WFs were transferred to susceptible tomato plants, a single WF per plant, and allowed a 24-hr transmission access period. At the end of the transmission period, before removal of the insects from the plants, the plants were screened for WFs persistence, i.e., the presence of live and active WFs on the plants. Following inoculation the plants were sprayed and kept in an insect proof greenhouse for 4 weeks, while appearance of TYLCV symptoms were monitored. TYLCV level was determined in source plants and in WFs following acquisition. The effect different plant hosts have upon virus transmission efficiency by WFs was assayed as well. There were significant differences in TYLCV transmission efficiency; the highest rate of transmission, 59%, was by WF which acquired the virus from susceptible plants. The lowest level of transmission, 17%, was by WF which acquired the virus from TY172. Thus, although TY172 can serve as a source of TYLCV in the field, the acquisition rate of the virus from TY172 was low compared to other resistant plant lines tested. The correlation between TYLCV accumulation level in the source plant and acquisition, and subsequently transmission, efficiency by whiteflies will be discussed.

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Research & Implementation Area: Section B. Viruses, Epidemiology, and Virus-Vector Interactions.

Dates Covered by the Report: 1999

Cucurbit Yellow Stunting Disorder Virus on Melon In the Lower Rio Grande Valley of Texas: Blame to *Bemisia?*

Cantaloupe and honeydew melons exhibited unidentified virus-like symptoms in the Lower Rio Grande Valley (LRGV) of Texas in the fall 1999. Plant materials were sent to Dr. J. McCreight, USDA-ARS in Salinas, CA, Dr. J. Brown, University of Arizona, and Dr. B. Falk, University of California at Davis. Eventually, the disease was identified as Cucurbit Yellow Stunting Disorder Virus (CYSDV) transmitted by Bemisia. CYSDV is a whitefly-transmitted virus, a member of closteroviruses. The vector whitefly is *Bemisia tabaci* (Gennadius) in Europe (Spain), and *B. argentifolii* Bellows & Perring in the US. CYSDV can be retained by the whitefly for at least 7 days, and has an experimental host range restricted to members of the family Cucurbitaceae. Unusual yellowing symptoms were widespread in cantaloupe and honeydew melon fields in the LRGV in late September. Plants with symptoms ceased growing and began to decline. Fruit from affected plants were lower in sugars than fruit from symptomless plants. Although we did not have the exact data to compare the number of fruits and yields from both virus affected plants and unaffected plants, as shown in Table 1, numbers of fruits from affected plants were much fewer than those from unaffected plants, and 30-50% of fruits in the affected plants were not marketable. Leaf samples exhibiting symptoms were sent to several plant virologists for diagnosis. With the efforts from all the scientists involved, the disease was eventually identified as the cucurbit yellow stunting disorder virus (CYSDV), which is recorded in the literature as transmitted by the silverleaf whitefly, *Bemisia argentifolii* (= *B. tabaci*). Yes, *B. argentifolii* is still one of the most important pests on cucurbits in the LRGV, and whiteflies were found on the plants showing virus disease symptoms. At present, we do not know how important CYSDV will be to the melon growers in the LRGV; how severe CYSDV may be on the spring melons; and how we can manage the CYSDV. We will appreciate any comments and information about the CYSDV.

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Research & Implementation Area: Section B: Viruses, Epidemiology, and Virus-Vector Interactions.

Dates Covered by the Report: 1999

Epidemiology Of Mungbean Yellow Mosaic Virus , A Yellow Plague Of Kharif Pulses

Yellow mosaic disease popularly known as yellow plague of Kharif pulses is currently the most important and wide spread in India. The pathogen Mungbean yellow mosaic virus is vectored by the whiteflies, *Bemisia tabaci* Genn. in circulative manner. In the last decade, there has been considerable progress in characterization of the virus, its relationship with the vector and the management aspects. However, certain aspects of epidemiology particularly the role of the weed hosts is not well understood.

Several naturally infected weeds and cultivated plants exhibiting yellow mosaic symptoms were tested for host range studies using the vector, *B. tabaci* and light microscopy (Azur A staining) technique. All except *Cajanus cajan* Mill sp. showed negative results. Of the various shapes and colours, bright yellow coloured cylindrical traps attracted the maximum whitefly adults. The population of whitefly increased with the increase in temperature and decreased in relative humidity. Heavy showers, frequent raining, strong winds and high RH were detrimental to the adults. The maximum adults were trapped in May and June with the minimum in November. The disease incidence was positively correlated with the whitefly population. Early spring and late rainy seasons planted curdbean crop showed less incidence of the disease. Increased row spacing increased the whitefly population as well as the disease incidence.

Investigator's Name(s): Philip A. Stansly.

Affiliation & Location: University of Florida, Southwest Florida Research and Education Center, Immokalee FL 34142.

Research & Implementation Area: Section B: Viruses, Epidemiology, and Virus-Vector Interactions.

Dates Covered by the Report: 1999

Impact and Management of Tomato Yellow Leafcurl Virus in Southwest Florida

We evaluated yield reduction caused by TLYCV infection in tomato as well as the mitigating effects of chemical and cultural practices aimed at controlling the whitefly vector, *Bemisia argentifolii*. Tomatoes were transplanted into beds covered with colored or reflecting mulches and in a separate experiment treated with combinations of systemic or insect growth regulator insecticides. Plants showing virus symptoms were regularly marked and harvested once individually. Yield varied with day of first symptom expression in a linear relationship. Total fruit weight was reduced 88% and 71% for plants showing symptoms at 30 and 33 days after transplanting respectively, compared to uninfected controls. Whitefly numbers were reduced and the appearance of virus symptoms was delayed by chemical treatments, especially those including soil-applied imidacloprid, in contrast to foliar applied thiamethoxam. Insecticidal effects on yield were consistent with virus incidence. These results were confirmed two earlier trials showing that soil applied imidacloprid or thiamethoxam provided better whitefly control than these same materials or acetamidprid applied to foliage from 2 to 6 times using the same or more total active ingredient. Aluminum mulch provided early protection from whiteflies and reduced virus incidence, although yields on black and aluminum mulch were not significantly different, probably because benefits from decreased virus incidence on aluminum were counterbalanced by lower soil temperatures. Thus, TYLCV had a devastating effect on tomato yield, especially when symptoms appeared early in plant development. These effects were mitigated through cultural and chemical practices aimed at delaying infection by protecting plants from the whitefly vector.

Investigator's Name(s): Gail C. Wisler & Arturo A. Cortez.

Affiliation & Location: USDA--ARS, Crop Research & Improvement Unit, Salinas, CA.

Research & Implementation Area: Section B: Viruses, Epidemiology, and Virus-Vector Interactions.

Dates Covered by the Report: 1998-1999

Differential Transmission Characteristics Among Four Whitefly Vectors of Tomato Chlorosis Crinivirus

Two bipartite, whitefly-transmitted viruses belonging to the genus Crinivirus in the family Closteroviridae have been characterized infecting tomato. These are Tomato infectious chlorosis virus (TICV) and Tomato chlorosis virus (ToCV). TICV is transmitted only by the greenhouse whitefly (GHWF; Trialeurodes vaporariorum), whereas ToCV is transmitted by the GHWF, the sweet potato whitefly (SPWF; *Bemisia tabaci* biotype A), the silverleaf whitefly (SLWF; *B. tabaci* biotype B; *B. argentifolii*), and the banded wing whitefly (BWWF; *T. abutilonea*). Since ToCV is transmitted by four vectors rather than one, it is expected to be more widespread than TICV. TICV was first identified as a distinct crinivirus in California in 1993. Since then it has been found in Italy, Taiwan and North Carolina. ToCV has been identified in Florida, Louisiana, Colorado, Spain, South Africa, and Taiwan. Identifications have been made by transmission using specific vectors and/or by dot blot hybridization using DIG-labeled riboprobes.

ToCV has a wide host range which includes 24 plant species in 7 plant families, and include some important crops and ornamentals, i.e., tomatillo (*Physalis ixocarpa*), tobacco, (*N. tabacum*), spinach (*Spinacea oleracea*), aster, calendula, and petunia. Unlike TICV, ToCV does not infect lettuce. Neither TICV nor ToCV infects members of the Cucurbitaceae.

Studies have been initiated to determine the transmission properties among the four whitefly vectors of ToCV. The efficiency of the four vectors differs significantly. Tests for transmission efficiency involved allowing aviruliferous whiteflies to feed on diseased plants in groups of 1, 5, 10, 20, and 40 per leaf cage for a 24 hr acquisition period, and then transferring them to *Physalis wrightii* Gray, an excellent indicator for most criniviruses tested. Ten replications were used for each test group and each test was replicated five times. All four vectors were tested concurrently. The SLWF is the most efficient vector. One SLWF transmitted ToCV 12.5% of the time. Five SLWFs transmitted at an efficiency of 48%, 10 transmitted at 40%, 20 at 88%, and 40 at 98%. The SLWF is expected to be an efficient vector because of its high incidence at the locations where ToCV was first identified in Florida. Surprisingly, the BWWF was equally as efficient as the SLWF at 7.5%, 40%, 43%, 84%, and 100% for 1, 5, 10, 20, and 40 whiteflies. In contrast, the SPWF and the GHWF were inefficient vectors. The efficiencies for the SPWF ranged from 0 to 68%, and the GHWF ranged from 0 to 28% for 1, 5, 10, 20, and 40 whiteflies, respectively. Preliminary tests using only the SPWF showed a persistence of 1 day. All SPWFs lost the virus during the first 24 hr feeding period. Additional studies are underway to determine the persistence, acquisition threshold, and inoculation threshold of all four whitefly vectors.

A third bipartite, whitefly-transmitted crinivirus in tomato has been identified from the Canary Islands. This new virus is very similar to ToCV according to the size of the double stranded RNA pattern and the fact that it is also transmitted by all four whitefly vectors. However, it is distinct from ToCV in that it infects lettuce. It is possible that other tomato infecting criniviruses exist. The vector specificity and transmission properties are valuable methods for identifying new viruses in combination with molecular and serological assays.

Research Summary

Section B: Viruses, Epidemiology, and Virus-Vector Interactions

Compiled by Robert L. Gilbertson and Robin Huettel

B.1. Identification and characterization of new or emerging whitefly-transmitted viruses and strains.

Two interesting developments were reported in this area. The first was the report of a new cucurbit-infecting geminivirus identified in the Imperial Valley of California. This virus was first observed causing symptoms of leaf crumpling and yellowing symptoms on leaves of watermelon volunteers in the Imperial Valley in the Fall of 1998. It was initially thought that these symptoms were caused by squash leaf curl virus, but DNA sequencing of PCR-amplified viral DNA fragments revealed that the virus was considerably different from squash leaf curl, and this new virus was named *Cucurbit leaf crumple virus* (CuLCrV). CuLCrV is typical of whitefly-transmitted geminiviruses (begomoviruses) in that it has a DNA-A and DNA-B component and these two components share an almost identical 200 bp sequence called the common region. CuLCrV was not detected in spring melons in 1999, but was found to be widespread in fall melons in 1999 in the Imperial Valley as well as in Blythe, CA and Yuma, AZ. In the fall 1999 melons, CuLCrV caused a crumpling, distortion and/or yellowing of leaves of watermelon, cantaloupe, and muskmelon. Interestingly, no symptoms were observed in honeydew melons. Significant progress has been made in the characterization of this virus (e.g., much of the DNA sequence of the virus has been elucidated) and tools are in hand for the monitoring of the virus in the spring and fall melons crops in 2000.

The second interesting development was the first report of *Cucurbit yellow stunting disorder virus* (CYSDV), a closterovirus in the Genus Crinivirus, in the United States. CYSDV was found in the Rio Grande Valley of Texas where it was associated with yellowing symptoms in older leaves of infected plants. Previously, CYSDV was only known to occur in Europe and the Middle East, but it may have been present in the Rio Grande Valley for some time. Because CYSDV is transmitted by the silverleaf whitefly, it poses a threat to melon production in the southeastern US. It will be important to monitor for CYSDV in 2000 to determine the geographic distribution and incidence in spring and fall melon crops.

B.2. Molecular epidemiology: Identification of economic viruses, plants, and reserviors, and determination of geographic distribution of viruses.

The application of molecular tools, including PCR with degenerate primers for whitefly-transmitted geminiviruses, squash blot hybridization with DNA probes, and DNA sequencing of PCR-amplified fragments allowed for the rapid identification of CuLCrV and the determination of the distribution of the virus in the Imperial Valley and Arizona. These tools will be used to monitor for CuLCrV in melons in spring and fall 2000. Infectious DNA clones of CuLCrV are being generated and will be used to determine the host range of this virus.

Similar molecular tools are being used in an attempt to characterize whitefly-transmitted geminiviruses infecting crop in Central America and the Caribbean. By identifying these viruses from a range of countries and crops, better strategies for disease management can be developed and/or implemented.

An excellent overview of whitefly-transmitted closteroviruses (Genus Crinivirus) was presented. A diversity of these viruses are now known to infect crop plants in the U.S. and throughout the world, including tomato infectious chlorosis ((TICV), tomato chlorosis virus (TCV), cucurbit yellow stunting disorder (CYSDV), and others. In contrast to whitefly-transmitted geminiviruses, which induce characteristic disease symptoms, the criniviruses induce yellow or interveinal yellowing symptoms that are confused with nutritional disorders, pesticide phytotoxicity, and physiological disorders. Significantly, many of these viruses have rather broad host ranges and can be found in weeds and other hosts. This makes the management of such viruses potentially problematic. A number of tests have now been developed for the detection of these viruses, including serological tests, DNA probes and degenerate PCR primers. These tools should be very helpful in detecting and monitoring for these viruses in the future.

B.3. Virus-vector interactions, factors affecting virus transmission, and basis for virus-vector specificity: determination of endosymbiont involvement in whitefly-mediated transmission.

Significant advances have been made in our understanding of the interaction of *Tomato yellow leaf curl virus* (TYLCV) and *B. tabaci* and this was the subject of the keynote presentation. For a summary of these advances, see the keynote address. Briefly, some of the topics that were presented included: evidence for

transovarial transmission of TYLCV from females to eggs (transmission rates ranging from 0-10%) and sexual transmission of TYLCV between male and female insects. Another very interesting topic was the role of the chaperonin protein GroEL, which is produced in whiteflies by endosymbionts, and may be involved in the protection of the virus in the insect body during it's journey from the gut to the salivary glands. Evidence was presented that the GroEL protein may directly interact with the viral capsid protein.

B.4. Strategies to reduce virus spread by management of cropping systems, reduced transmission frequencies, and other potentially effective approaches.

An update was presented on the use of living ground covers and silver plastic reflective mulches to reduce virus spread by whiteflies. It was reported that both living ground covers and silver mulch can reduce the spread of virus in Costa Rica and Florida, but only under conditions of low to moderate virus pressure. Of the living ground covers tested, perennial peanuts seemed to be the best, but silver plastic reflective mulch was the best for slowing spread of virus.

B. 5. Control of virus diseases; development of virus resistant germplasm through conventional and engineered/molecular approaches. Define prospective strategies for selecting candidate viruses, identifying specific virus diseases to target, and prioritize specific crops and cultivars for protection approaches.

An interesting presentation was made regarding the influence of varieties resistant to TYLCV on the epidemiology of the virus. Tomato varieties resistant to TYLCV are now commercially available and some of these provide high levels of resistance. Research in Israel suggests that use of highly resistant varieties (e.g., TY172) will reduce the rate of virus transmission compared to susceptible cultivars. However, moderately resistant cultivars (e.g., Fiona) may actually enhance virus transmission and actually enhance epidemics of TYLCV because, when infected, these cultivars provide better sources of inoculum over longer periods of time compared with susceptible cultivars, which become severely diseased or die thereby making them poor sources of inoculum. These perhaps unexpected findings may influence how management strategies are developed.

A report was also presented on the continued screening of cotton varieties, under field conditions in the Imperial Valley of California, for resistance *to Cotton leaf crumple virus* (CLCrV). A number of lines continue to look promising, particularly line C95-387, which showed no symptoms of infection and in which no virus was detected. Two other lines, C95 483 and C95 383 also showed resistance to CLCrV. Although leaf crumple disease of cotton is no a major problem in the U.S., these resistant varieties could be very useful in India or Pakistan where the devastating *cotton leaf curl virus* (CLCV) causes significant losses to cotton production. Thus, it seems important to screen these materials in India or Pakistan to see if they have any resistance to the CLCV.

Research approach 6. Pursue specific genetic and biological basis for variability in whitefly biotypes, strains, and species; determine impact of different genotypes/phenotypes on whitefly-mediated transmission and on the epidemiology of virus diseases.

There were no reports for this area.

Technology transfer:

There is strong interest in evaluating the CLCrV resistant lines in Pakistan or India where the cotton leaf curl virus is threatening cotton production. The use of degenerate PCR primers for whitefly-transmitted geminiviruses and criniviruses help in the rapid identification and characterization of a new melon-infecting geminivirus in the Imperial Valley and the first report of cucurbit yellow stunt disorder in the lower Rio Grande Valley of Texas. TYLCV-resistant tomato cultivars are now available and these allow for respectable yields in area with high incidences of TYLCV.

Table B. Viruses, Epidemiology and Virus Vector Interactions.

Research Approaches	Year 1 Goals Statement	Progress Achieved Yes	No	Significance
Identification and characterization of new or emerging whitefly-transmitted viruses and strains.	Monitor crops for presence of whitefly-transmitted diseases, and determine relative disease incidence. Begin virus identification and strain differentiation.		X	Rapid techniques are available for identification and characterization of geminiviruses through sequencing of PCR-amplified viral DNA fragments. This approach was used to show 98% sequence identity between the tomato yellow leaf curl gemini virus (TYLCV) from the Dominican Republic and an Eastern Mediterranean virus strain indicating that the virus was probably introduced on tomato transplants from the Eastern Mediterranean area The use of such sequences in comparisons of viruses are important in establishing their relatedness and origin. Several other assays are available for rapid detection of geminiviruses such as dot blot and squash blot hybridization analysis.
Molecular epidemiology: identification of economic viruses, host plants, and reservoirs, and determination of geographic distribution of viruses.	Monitor and identify host plants, virus reservoirs in affected areas. Linkages to diagnostic methods for virus ID and tracking.		X	The use of squash blot analysis using a TYLCV-specific DNA probe to assess the role of weeds as hosts in the Dominican Republic showed that they were not infected with TYLCV and not significant molecular sources for the virus. TYLCV newly discovered in Florida was also 98% identical to the Dominican Republic strain. Geminiviruses, are known throughout the world and distinct viruses are known to occur in many countries. For instance, tomato mottle virus ToMoV) was first detected in Florida in 1989 and is thought to have originated from that state.

Table B. Viruses, Epidemiology and Virus Vector Interactions. (Continued)

Research Approaches	Year 1 Goals Statement	Progress Achieved Yes	No	Significance
Virus-vector interactions, factors affecting virus transmission, and basis for virus-vector specificity; determination of endosymbiont involvement in whitefly-mediated transmission.	Initiate studies on virus-vector interactions and on basis for the specifcity of whitefly-mediated geminivirus transmission.		X	Studies on feeding duration and position has demonstrated differences in aphids and whiteflies. These differences may determine why some geminiviruses are transmitted by one group and not the other. The use of the autoflourescent GFP gene, in tracking the virus movement and replication in plants indicated that a cell to cell movement of the virus occurred and the virus was not phloem limited. Understanding the movement of the virus in terms of insect feeding behavior may play a role in developing resistant varieties.
Strategies to reduce virus spread by management of cropping systems, reduced transmission frequencies, and other potentially effective approaches.	Develop approaches to managing cropping systems to reduce vector densities to decrease transmission frequency and inoculum sources, taking into account weed and crop reservoirs in disease incidence and distribution.		X	Host-free practices used in the Dominican Republic for TYLCV have been successful in reducing the incidence of this disease. In Florida, management of whiteflies with insecticides, field sanitation, and clean transplants has reduced the incidence of ToMoV. In whitefly reduction studies using biological control based IPM, there was a 10% reduction in geminiviruses in squash (See Table D).
Control of virus diseases: development of virus resistant germplasm through conventional and engineered/ molecular approaches. Define prospective strategies for selecting candidate viruses, identifying specific virus diseases to target, and prioritize specific crops and cultivars for protection approaches.	Define strategies for resistance efforts. Identify target viruses. Identify germplasm with virus resistance. Initiate efforts toward defining prospective engineered resistance strategies. Identify candidate crops and recipient cultivars.			Resistance to the geminivirus, bean dwarf mosaic virus (BDMV), was found in □Pinto□ bean variety, Othello. Using the GFP gene as a marker, virus infection in this variety was compared with that in a susceptible variety. In the resistant variety, there was a collapse of tissue at the infection site and continuing necrosis in the vascular areas indicating a hypersensitive reaction to the virus. The gene(s) involved in this response may be a source of resistance to this virus either through conventional breeding efforts or by identifying the gene(s) involved. In cotton, some resistance to the cotton leaf crumple virus was reported (See Table F).

Table B. Viruses, Epidemiology and Virus Vector Interactions. (Continued)

Research Approaches	Year 1 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Pursue specific genetic and biological basis for variability in whitefly biotypes, strains, and species; determine impact of different genetypes/phenotypes on whitefly-mediated transmission and on the epidemiology of virus diseases.	Identify differences in species, strains and biotypes with respect to transmission, host range, mating compatabilities, molecular variability, and map the biogeographic distribution of distinct types within the *B. tabaci* species complex.			No reports in this area.

Table B. Viruses, Epidemiology and Virus Vector Interactions.

Research Approaches	Year 2 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Identification and characterization of new or emerging whitefly-transmitted viruses and strains.	Virus identification and characterization. Develop methods for identifying causal agents and for tracking viruses and strains using molecular methods.	X		1. Significant progress has been made in the detection and characterization of tomato yellow leaf curl geminivirus in Florida. A comprehensive survey of the incidence and distribution of TYLCV has been made. 2. Evidence has been obtained of a synergistic interaction among three geminivirus DNA components associated with chino del tomate disease of tomato (pepper huasteco geminivirus [PHV] DNA-A and DNA-B and another distinct DNA-A component, chino-A). Here, the disease symptoms induced in three hosts (Nicotiana benthamiana, tomato, and pepper) by PHV plus the chino-A are much more severe than symptoms induced by PHV alone. These results establish that (i) chino del tomate disease may be caused by a complex of geminivirus components, (ii) that complexes of geminivirus components can dramatically influence disease symptom expression and (iii) that identification of geminiviruses based on disease symptoms alone is difficult. 3. Tomato geminivirus diseases in Guadeloupe are caused, at least in part, by a strain of potato yellow mosaic geminivirus (PYMV).

Table B. Viruses, Epidemiology and Virus Vector Interactions.

Research Approaches	Year 2 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Molecular epidemiology: identification of economic viruses, host plants, and reservoirs, and determination of geographic distribution of viruses.	Continue field studies. Determine economic input of diseases on crop production and associated losses.	X		1. The spread of TYLCV in Florida has been extensively documented. The virus has been disseminated throughout the state, including some northern counties. The highest incidences of TYLCV have been correlated with high populations of whiteflies. Extensive host range studies are being conducted with TYLCV in Florida, and TYLCV has been found to infect and cause disease in petunia and common bean. Detection in petunia could have serious implications in terms of exporting this ornamental plant. 2. Efforts are being conducted to understand how TYLCV survives in the Dominican Republic during the three-month whitefly host-free period. Using a polymerase chain reaction test to determine the relative contamination of whiteflies with TYLCV, it was found that by the end of the tomato-growing season, TYLCV was readily detected in whiteflies collected from all tomato fields tested. However, within one month of the host-free period, the amount of virus detected in whiteflies collected from plants surrounding tomato fields decreased tremendously. By the end of the host free period, little or no virus could be detected in whiteflies. These results suggest that whiteflies themselves are not likely to be the primary way in which the virus survives during the host-free period. Weeds and other plants in and around fields during the host-free period were then collected and tested for TYLCV using PCR. A number of weeds were found to be symptomless carriers of TYLCV. These results suggest that such symptomless hosts may be the primary way that the virus survives during the host-free period.

Table B. Viruses, Epidemiology and Virus Vector Interactions. (Continued)

Research Approaches	Year 2 Goals Statement	Progress Achieved Yes	No	Significance
Virus-vector interactions, factors affecting virus transmission, and basis for virus-vector specificity; determination of endosymbiont involvement in whitefly-mediated transmission.	Determine specific cellular and molecular factors involved in virus transmission. Study role of endosymbionts in virus acquisition and transmission.		X	Strategies to reduce virus spread by management of cropping systems, reduced transmission frequencies, and other potentially effective approaches. Continue studies of management approaches for disease abatement. Interdisciplinary studies in conjunction with whitefly control methods in Sections B and C.
Strategies to reduce virus spread by management of cropping systems, reduced transmission frequencies, and other potentially effective approaches.	Continue studies of management approaches for disease abatement. interdisciplinary studies in conjunction with whitefly control methods in Sections B and C.	X		In Costa Rica, experiments conducted using living covers (such as coriander and perennial peanuts) and silver plastic mulch demonstrated that these strategies reduced the incidence of geminivirus infection of tomato under moderate whitefly/ geminivirus pressure, but not under high pressure. Thus, living covers and/or silver plastic represent a promising management tool, but one that needs to be used in combination with other practices that lead to reduced inoculum pressure. In the Dominican Republic, the mandatory whitefly host-free period continues to provide an effective management tool for TYLCV. There is a lag period of approximately one-month after planting tomatoes before TYLCV appears and this lag period allows for early-planted tomatoes to provide good yields. This strategy, together with the use of insecticides and tolerant varieties for late season planting, have allowed for the almost complete recovery of the processing tomato industry in the Dominican Republic.

Table B. Viruses, Epidemiology and Virus Vector Interactions. (Continued)

Research Approaches	Year 2 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Control of virus diseases: development of virus resistant germplasm through conventional and engineered/molecular approaches. Define prospective strategies for selecting candidate viruses, identifying specific virus diseases to target, and prioritize specific crops and cultivars for protection approaches.	Continue to define suitable strategies for determining target viruses. Isolate and characterize virus-resistant germplasm. Continue work toward engineered resistance in target crops and selected viruses.	X		1. Cotton varieties have been screened under field conditions in the Imperial Valley of California for resistance to cotton leaf crumple geminivirus (CLCrV). A number of lines looked promising, particularly C95-387, which showed no symptoms of infection and in which no virus was detected. Two other lines, C95483 & C95383 also showed potential resistance to CLCrV. 2. Efforts are underway to identify tomato germplasm that is resistant to TYLCV as well as to develop genetically engineered tomatoes with resistance to TYLCV.
Pursue specific genetic and biological basis for variability in whitefly biotypes, strains, and species; determine impact of different genetypes/phenotypes on whitefly-mediated transmission and on the epidemiology of virus diseases.	Continue to study differences in species/strains/biotypes with respect to transmission, host range, mating compatibilities, molecular variability. Determine molecular basis of observed variability in biological, molecular & genetic terms. Infer molecular phylogenies from molecular markers.		X	

Table B. Viruses, Epidemiology and Virus Vector Interactions.

Research Approaches	Year 3 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Identification and characterization of new or emerging whitefly-transmitted viruses and strains.	Continue etiological studies and virus characterization. Apply molecular diagnostics to virus identification and evaluation of disease incidence and virus distribution.	X		1.A new cucurbit-infecting geminivirus, *Cucurbit leaf crumple virus* (CuLCrV) was identified in the Imperial Valley of California. This virus causes leaf crumpling and yellowing in watermelon, cantaloupe, and muskmelon, but no symptoms were observed in honeydew melons. Very high incidences of the virus were detected in fall melons in the Imperial Valley and the virus was detected in melons with leaf crumple symptoms from Blythe, CA and Yuma, AZ. Significant progress has been made in the characterization of this virus (e.g., much of the DNA sequence of the virus has been elucidated) and tools are in hand for the monitoring for the virus in the spring and fall melon crops in 2000. 2.*Cucurbit yellow stunting disorder virus* (CYSDV), a closterovirus in the Genus *Crinivirus*, was identified for the first time in the United States in the Rio Grande Valley of Texas. CYSDV is transmitted by the silverleaf whitefly. Previously, CYSDV was only known to occur in Europe and the Middle East. Like most of the so-called yellowing viruses, this virus causes yellowing symptoms in older leaves of infected melons. These symptoms can resemble nutritional deficiencies. Thus, infections by these viruses can be hard to diagnose. Molecular tools are available for detection of CYSDV and other related closteroviruses, particularly a degenerate PCR primer pair designed based upon the heat shock protein-like gene that is found in all of these viruses. It will be important to carefully monitor the spread of this virus in Texas and to look for it in other melon growing areas.

Table B. Viruses, Epidemiology and Virus Vector Interactions.

Research Approaches	Year 3 Goals Statement	Progress Achieved Yes	No	Significance
Molecular epidemiology: identification of economic viruses, host plants, and reservoirs, and determination of geographic distribution of viruses.	Establish geographic distribution of viruses and identify sources of inoculum. Assess role of alternative host virus reservoirs on spread of diseases.	X		1.The distribution of CuLCrV in the Imperial Valley of California in 1999 was extensively documented using PCR and degenerate primers for whitefly-transmitted geminiviruses and using squash blot hybridization with a general probe for these viruses. The results of these analyses revealed that the virus had spread extensively by late fall 1999 and that it was infecting muskmelons throughout the Imperial Valley. It will be important to use these tools to monitor for CuLCrV in melons in spring and fall 2000. Infectious DNA clones of CuLCrV are being generated and will be used to determine the host range of this virus. 2.Molecular tools are now in place to study the distribution of whitefly-transmitted geminiviruses in Central America and South America. This information will be important in order to develop resistance strategies. 3.Many criniviruses have the capacity to infect weed and other hosts. Thus, it will be important to carefully monitor areas in which CYSDV has become established to assess the potential for weed and alternate hosts to contribute to the epidemiology of this disease. Findings from this work will impact management strategies.

Table B. Viruses, Epidemiology and Virus Vector Interactions. (Continued)

Research Approaches	Year 3 Goals Statement	Progress Achieved Yes	No	Significance
Virus-vector interactions, factors affecting virus transmission, and basis for virus-vector specificity; determination of endosymbiont involvement in whitefly-mediated transmission.	Continue studies in progress to determine specific factors involved in virus transmission, and the role of endosymbionts in virus acquisition and transmission.	X		Important advances have been made in understanding the interaction of *Tomato yellow leaf curl virus* and *B. tabaci*. There is now evidence for transovarial transmission (rates ranging from 0-10%) and sexual transmission between male and female insects. How these finding impact the epidemiology of the virus and disease management remain to be determined. It was also reported that a chaperonin protein produced in whiteflies by endosymbionts called GroEL may be involved in the protection of the virus in the insect body during it's journey from the gut to the salivary glands. This may involve an interaction between the GroEL chaperonin protein and the viral capsid protein.
Strategies to reduce virus spread by management of cropping systems, reduced transmission frequencies, and other potentially effective approaches.	Continue studies of management approaches for disease abatement. Focus on interdisciplinary studies in conjunction with whitefly control methods in Sections B and C.	X		It was reported that living ground covers and silver plastic reflective mulches can reduce virus spread in Costa Rica and Florida, but only under conditions of low to moderate virus pressure. Of the living ground covers tested, perennial peanuts seemed to be the best. Overall, silver plastic reflective mulch was the best for slowing spread of virus.

Table B. Viruses, Epidemiology and Virus Vector Interactions. (Continued)

Research Approaches	Year 3 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Control of virus diseases: development of virus resistant germplasm through conventional and engineered/molecular approaches. Define prospective strategies for selecting candidate viruses, identifying specific virus diseases to target, and prioritize specific crops and cultivars for protection approaches.	Further identification of resistant germplasm and develop new methods of incorporating resistance into crop plants. Evaluate resistance strategies with respect to broad spectrum or virus-specific protection.	X		1.Tomato varieties resistant to TYLCV are now commercially available and some of these provide high levels of resistance. Research in Israel suggests that use of highly resistant varieties (e.g., TY172) will reduce the rate of virus transmission compared to susceptible cultivars. However, moderately resistant cultivars (e.g., Fiona) may enhance virus transmission and actually enhance epidemics of TYLCV because the provide better sources of inoculum over longer periods of time compared with susceptible cultivars, which become severely diseased or die thereby making them poor sources of inoculum. These findings may influence how management strategies are developed. 2.Cotton varieties continue to be screened under field conditions in the Imperial Valley of California for resistance *to Cotton leaf crumple virus* (CLCrV). A number of lines continue to look promising, particularly line C95-387, which showed no symptoms of infection and in which no virus was detected. Two other lines, C95 483 and C95 383 also continue to show potential resistance to CLCrV. It will be very important to screen these materials in India or Pakistan to see if they have any resistance to the devastating cotton leaf curl virus, another whitefly-transmitted geminivirus that infects cotton. 3.Progress has been made in the generation of transgenic crops that are resistant to geminivirus infection. The major strategy that has been pursued to date is that of pathogen-derived resistance in which a wild-type or mutated virus gene or sequenced is introduced into the crop plant of choice. The idea is that expression of the viral sequence/ protein will interfere with the normal life cycle of the virus and, thus, interfere with the viral infection process. A number of viral genes have been evaluated to date including: capsid protein, replication-associated protein and movement protein. Promising levels of resistance have been obtained, though no plants have been reported to be highly resistant (i.e., immune).

Table B. Viruses, Epidemiology and Virus Vector Interactions. (Continued)

Research Approaches	Year 3 Goals Statement	Progress Achieved		Significance
		Yes	No	
****Pursue specific genetic and biological basis for variability in whitefly biotypes, strains, and species; determine impact of different genetypes/phenotypes on whitefly-mediated transmission and on the epidemiology of virus diseases.**	Continue with work from previous years. Study impact of biotypes, strains, and species differences in the disease spread, crop damage, and specific control measures to reduce whitefly vector populations. Linkages with biological and chemical control sections.		X	This research approach should be transferred to section A

** Transfer to Table A 3/31/2000

Reports of Research Progress

Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods

Co-Chairs: James Brazzle and John Palumbo

Investigator's Name(s): D. H. Akey and T. J. Henneberry.

Affiliation & Location: USDA, ARS, Western Cotton Research Laboratory, Phoenix AZ 85040-8803.

Research & Implementation Area: Section C: Chemical Control, Biorationals and Pesticide Application Technology

Dates Covered by the Report: June-September 1999

Azadirachtin (as Bollwhip™), a Biorational Agent Against the Silverleaf Whitefly, *Bemisia argentifolii*, in Field Trials in Upland Cotton in Arizona

Deltapine NuCOTN 33^B was planted and furrow irrigated in plots 109 ft. in length and 12 rows across (40-in. rows). Plots were separated by 2 fallow rows and 20 ft alleys. Spray applications were made by a ground boom with 5 nozzles/row, 1 overhead, and 2 swivel nozzles angled upward on a drop on each side of the row, at 250 psi and 30 gal/ac. Eight sprays were applied weekly beginning July 22 and ending September 9. The 1999 cotton season was a good year in respect to abiotic factors favorable to growing cotton. Silverleaf whitefly populations were present in cotton from mid to late season.

Azadirachtin as Bollwhip™ (Thermo Trilogy Corp.) was used in a 4.5% formulation at 6 oz product/ac. This treatment was part of a 10-treatment random block design that included a "Best Agricultural Practice" (BAP) treatment, and an embedded control treatment, plus a single 1-ac block control. Buprofezin (Applaud™ 70 WP, AgrEvo, 0.35 lb. AI/ac) was the 1st BAP treatment applied followed by pyriproxyfen (Knack™ 0.86 EC, Valent USA, 0.054 lb. AI/ac).

Whitefly eggs, small nymphs, and large nymphs were sampled from one leaf taken from each of 10 plants per plot, from the 5th main-stem node down from the 1st expanded terminal leaf. Each sample was counted from a 2.22 cm diameter disk taken from the leaf between the main (central) and the adjacent lateral vein. All whitefly adults were counted on the 5th main-stem leaf abaxial surface sampled from 30 leaves/plot, using the leaf-turn method; the first 10 were from the same plants used for immature samples. Weekly sweeps (25/plot) were taken in all plots for predators, parasites, the thrip, *Frankliniella occidentalis*, and *Lygus* (primarily *hesperus*).

Azadirachtin as Bollwhip™ had seasonal efficacies (as % reduction from block control) against whitefly immatures as follows: eggs, 37 %; small nymph, 32 %; and large nymphs, 66 %, respectively. These efficacy rates were significant at $P<0.001$ by ANOVA and $P< 0.05$ mean separation by LSD. Buprofezin application followed by pyriproxyfen 2 weeks later provided season-long control with egg, small nymph, and large nymph efficacies of 42, 75, and 95 %, respectively. The mean number of large nymphs in the Bollwhip™ plots did not exceed treatment threshold for the season (University of AZ recommendations).

Investigator's Name(s): D. H. Akey and T. J. Henneberry.

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Research & Implementation Area: Section C: Chemical Control, Biorationals And Pesticide Application Technology

Dates Covered by the Report: June-September 1999

Effect on *Lygus* of Biorationals (Insect Growth Regulators and Entomopathogenic Fungi) Used for Control of the Whitefly *Bemisia argentifolii*, in Field Trials in Upland Cotton in Arizona

Deltapine NuCOTN 33^{B} was planted and furrow irrigated in plots 109 ft. in length and 12 rows across (40-in. rows). Plots were separated by 2 fallow rows and 20 ft alleys. Spray applications were made by a ground boom with 5 nozzles/row, 1 overhead, and 2 swivel nozzles angled upward on a drop on each side of the row, at 250 psi and 30 gal/ac. Eight sprays were applied weekly beginning July 22 and ending September 9. The 1999 cotton season was a good year in respect to abiotic factors favorable to growing cotton. Silverleaf whitefly populations were present in cotton from mid to late season and *Lygus* (primarily *hesperus*) was present during the entire season. Weekly sweeps (25 per plot) were taken in all plots for *Lygus*, predators, parasites, and the thrip, *Frankliniella occidentalis*.

Biorational entomopathogenic fungi used included: *Beauveria bassiana,* as Naturalis®L (Troy Biosciences Inc.) 10 oz. Product/ac, 2.3×10^{7} conidia/ml; as Mycotrol® ES (Mycotech Corp.), 0.5 pt/ac, 2×10^{13} spores/qt, and *Paecilomyces fumosoroseus* as PFR- 97™ (Thermo Trilogy Corp.), 0.025 lb /gal., 1×10^{9} CFU (spores)/ gm equivalent 20% product. All three of these products were used at full rate for multiple applications.

Biorational insect growth regulators used were at full rate as single or multiple applications and included: azadirachtin as Bollwhip™ (Thermo Trilogy Corp.), 4.5% formulation 6 oz product /ac.(note, other action modes also); buprofezin as Applaud™ 70 WP (AgrEvo), 0.35 lb. AI/ac; and pyriproxyfen as Knack™ 0.86 EC (Valent USA) 0.054 lb. AI/ac. These treatments were part of a 10-treatment random block design that included a "Best Agricultural Practice" (BAP) treatment, and an embedded-control treatment, plus a single 1-ac block control. Treatment efficacy was measured as mean percent reduction from the block control.

Effects of biorational entomopathogenic fungi on *Lygus* nymphs and adults, respectively, were as follows: Naturalis® L, efficacies of 11 and 17 % (neither significant); Mycotrol® ES, efficacies of 0 and 22 % (latter significant at $P<0.05$ by ANOVA and LSD), and PFR- 97™, efficacies of 0 and 22 % (latter significant at $P<0.05$ by ANOVA and LSD).

Effects of biorational insect growth regulators on *Lygus* nymphs and adults, respectively, were as follows: Bollwhip™, efficacies of 14 (not significant) and 15 %, (significant at $P< 0.05$ by ANOVA,), Applaud™ , 0%-no efficacy, and Knack™, efficacies of 0 and 36% (neither significant).

None of the treatment efficacies sufficiently controlled *Lygus*. The damage resulted in severe yield losses. However, the *Lygus* populations were very high in the entire region and convention chemical control was also unable to stop *Lygus* and most if not all cotton in the region suffered substantial yield losses. The treatments reported here need to be retested in trials with more moderate *Lygus* populations representative of endemic rather than epidemic levels.

Investigators' Name(s): Frank J. Byrne[1], Nilima Prabhaker[1], Nick C. Toscano[1], Ralf Nauen[2] & Steve Castle[3]

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Research & Implementation Area: Section C: Chemical Control, Biopesticides, Resistance Management, and Application methods.

Dates Covered by the Report: 1999

Studies on Imidacloprid Resistance in *Bemisia* Whiteflies

Imidacloprid is a nicotinic acetylcholine receptor agonist belonging to the chloronicotinyl class of insecticides, and is one of the most effective insecticides currently available for the control of *Bemisia* infestations. However, as with any insecticide, over exposure of insect populations can result in the development of resistance. Resistance to imidacloprid has now been reported in both field and laboratory populations. In Almeria in Southern Spain, heavy reliance on imidacloprid to control the spread of geminivirus diseases in tomatoes has resulted in the development of resistant populations. Resistance has also developed in populations maintained in the laboratory under continuous selection pressure.

Thus far, there are no accounts of biochemical mechanisms involved in conferring resistance to imidacloprid in *Bemisia*. In our laboratory, we are investigating the potential role of MFO-based metabolism using radiolabelled (^{14}C) imidacloprid. An assay has been developed which will detect metabolites of imidacloprid. Microsomal preparations of susceptible *Bemisia* collected from two locations in Imperial Valley have so far been compared with similar preparations from housefly abdomens. We detected no metabolites in experiments using these field strains, whereas the houseflies readily produced significant amounts of mono-hydroxy derivatives (resulting from hydroxylation of the imidazolidine ring at positions 4 and/or 5), and to a lesser extent the olefin.

Our preliminary data suggest that there is little potential for the metabolism of imidacloprid by susceptible whitefly populations. The next stage of the study will involve comparisons of resistant whitefly populations from both laboratory and field locations.

Investigator's Name(s): [1]C. C. Chu, [1]T. J. Henneberry, [2]B. E. Mackey, & [3]H. H. Perkins.

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Research & Implementation Area: Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

Dates Covered by the Report: 1993 - 1996

Effects of Silverleaf Whitefly Infestation on Upland Cotton Yield and Honeydew Lint Contamination and Establishment of Action Threshold in the Imperial Valley, California

In 1993 and 1994, we conducted studies to determine the effect of chemical control on silverleaf whitefly populations, upland cotton yield and honeydew contamination. Different population densities of silverleaf whiteflies were established with fenpropathrin-acephate insecticide mixture treatments during the growing season at the Irrigated Desert Research Station, Brawley, CA. Regression analyses showed that the highest cotton lint yields and lowest lint stickiness occurred when silverleaf whitefly densities were 0.3 and 1.3 nymphs/cm^2 of leaf disk, respectively or 4.1 and 7.5 adults per leaf-turn from 5th main stem node leaves from terminals, respectively. In 1995 and 1996, we verified the 4 adults per leaf-turn (the highest cotton lint yields) action threshold with 15 adults (the highest economic return) per leaf-turn and an untreated control. Results showed that initiating chemical control at 4 adults per leaf-turn produced higher lint yields and less lint stickiness compared to initiating chemical control at 15 adults per leaf-turn. Higher lint yields and lower lint stickiness occurred at both treatment levels compared to untreated cotton. Initiating treatments at 15 adults per leaf-turn required 2 to 3 applications and initiating control at 4 adults per leaf-turn required 5 to 6 applications during 1995 and 1996, respectively. Economic returns based on insecticide costs and lint yield were highest when cottons were treated at 4 adults per leaf-turn. Cotton lint stickiness was considered in the analyses and discounts for sticky cotton could significantly reduce net monetary returns.

Investigator's Name(s): Gary W. Elzen.

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Research & Implementation Area: Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

Dates Covered by the Report: 1998-1999

Laboratory Toxicity of Selected Insecticides to Silverleaf Whiteflies (Preliminary Results)

Formulated insecticides tested were abamectin [Agri-Mek 0.15 emulsifiable concentrate (EC)], tebufenozide [Confirm 2.0 flowable (F), imidacloprid [Provado 1.6 F}, chlorfenapyr [Pirate 3 suspension concentrate (SC), neonicotinyl [CGA-293343 25.0 wettable granule (WG), pymetrozine [Fulfill 50 WG], endosulfan (Phaser 3 EC)], and buprofezin {Applaud 70.0 wettable powder (WP)].

Silverleaf whitefly eggs on cotton, cabbage, and sweet potato were treated with recommended rates of insecticides using a laboratory spray chamber. Rates were selected based on recommendations in an appropriate field guide or from manufacturer's recommendations in the case of newer or non-registered materials. Development was followed for ten days post-treatment. One application of tebufenozide, imidacloprid, or chlorfenapyr to cotton resulted in mortality exceeding 80%. However, treatment with abamectin resulted in less than 9% mortality on cotton. Results varied by type of host plant treated. Further experiments are planned.

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Research & Implementation Area: Section C: Chemical Control, Biopesticides, Resistance Management, and Application Technology.

Dates Covered by the Report: 1999

Efficacy and Persistence of Platinum, Actara and Admire for Management of Silverleaf Whitefly on Cantaloupe in South Texas

The silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring, continues to be one of the most important pests on cucurbits in south Texas. One of the most effective insecticide, imidacloprid (Admire), has been used for many years. Although it is still effective against the whitefly up to 9-11 weeks when it is applied at planting, growers cannot rely on only one insecticide. Alternative materials are essential needed. Thiamethoxam (Platinum and Actara) is one of the newer insecticides effective against the whitefly. The objective of this experiment was to determine the efficacy and persistence of these materials against silverleaf whitefly on melon in south Texas. The cantaloupe was seeded in the field on February 9, 1999. Each plot was 30 ft long with two separate rows (80 in wide), and 30 plants each. The plots were arranged in a randomized complete block design with 4 replications. The seven treatments were 1. Platinum (0.90 fl. oz/1000 ft) dripped at planting; 2. Platinum (0.65 fl. oz/1000 ft) dripped at plating; 3. Actara (38.9 g ai/ac) sprayed for 3 times; 4. Admire (1.1 fl. oz/1000 ft) dropped at planting; 5. Admire (1.1 fl. oz/1000 ft) dripped in mid-season; 6. Admire (1.1 fl. oz/1000 ft) dripped at planting and mid-season; and 7. Untreated control. Platinum were dripped 15 cm (6 in) deep in the soil through the irrigation system at planting on February 22, 1999. There were three treatments for Admire, dripped at planting, at mid-season on April 13, and dripped both at planting and mid-season. Actara was sprayed 3 times, on March 24, April 7, and 22, 1999. Sampling was initiated 4 weeks (on March 8) after planting. Ten plants per plot were randomly selected, whitefly adults from the third leaf from the apical meristem were counted by leaf turn method. Plants were sampled in 7-day intervals for 11 times. When plants were younger than 6 leaves, nymphs (all instars), and pupae (re-eyed nymphs) per 4 leaf-discs (2-cm diameter) per leaf from the oldest leaf were counted. When plants have >6 leaves, nymphs on the 4th~5th leaf proximal to the base of the plant were counted. Plant damage, including sooty mold on foliage, overall plant damage, fruit weight and soluble sugar, was evaluated.

At the early season, whitefly population was high on untreated treatments (in treatment 5, Admire was not used until the mid-season on April 13, and Actara was not sprayed until March 23). Silverleaf whitefly population was significantly lower on the plants treated with Platinum (2 rates) and Admire (dripped at planting). Actara, after the first application on March 23, whitefly population dropped immediately to a low level (about 1 adult per leaf), in 1 week, and kept at low level throughout the season. All insecticide-treated plants had significantly lower whitefly population than those on untreated plants. At late or the end of season, whitefly population on insecticide-treated plants was often greater than on the untreated plants because the whiteflies killed the untreated plants, causing the whiteflies to relocate their feeding plants to the treated, green plants. Number of eggs on untreated plants was significantly greater than that on all insecticide-treated plants from the mid- to late, and to the end of season. Numbers of nymphs and pupae of silverleaf whitefly increased at a relatively slow pace before the mid-season. Nymphs and pupae on untreated plants increased sharply from late April, whereas those on insecticide-treated plants increased, but at a very slower pace. Among the insecticide treatments, Actara, Admire at planting and at planting and mid-season, Platinum at higher rate and Admire at mid-season had slightly fewer nymphs and pupae than those on the plants treated with Platinum at lower rate. Sooty molds on leaves were lowest on the plants treated with Actara, Admire at planting and at planting- mid-season, Platinum at higher rate, followed by Platinum at lower rate and Admire at mid-season. In the untreated plots, almost all leaves and melons were covered by sooty mold and honeydew, and the leaves dried at the end of the season. Plants treated Platinum and Admire resulted significantly higher yields, and higher percentage of sugar than those of untreated plants. Numbers of melon per plot varied greatly and were significantly different. Plots treated with Platinum had the highest number of larger melons than other treatments, followed by Actara, and Admire treatments. In contrast, untreated plots had fewest large melons and highest number of small melons. Similarly, treated plants had higher yield than untreated plants.

Investigator's Name(s): Steven E. Naranjo[1] & Nilima Prabhaker[2].

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Research & Implementation Area: Section C: Chemical Control, Biopesticides, Resistance Management and Application Methods.

Dates Covered by the Report: January 1999 - December 1999

Toxicological Studies of Two Insect Growth Regulators on the Predator *Geocoris punctipes*

Laboratory experiments were conducted to evaluate the direct effects of two insect growth regulators (IGR), buprofezin (chitin synthesis inhibitor) and pyriproxyfen (JH analog), on survival and reproduction of *Geocoris punctipes*. Topical and contact residue assays were performed on both 5th instar nymphs and on 5-10 day old adults. Over a wide range of doses buprofezin had no effect on survival or reproduction of 5th instar nymphs or adults based on topical or contact residue assays. Topical assays with pyriproxyfen on 5th instar nymphs yielded an LD50 and LD90 of 3520 and 47,186 ppm, respectively. Concentrations of field applications are ca. 2700 ppm. At doses > 2700 ppm most nymphs molted to the adult stage but many had wing deformities that prevented successful mating and reproduction. Contact residue assays on 5th instar nymphs yielded an LD50 and LD90 of 706 and 2307 ppm, respectively. Again, most of the affected nymphs molted to the adult stage but had wing deformities. Pyriproxyfen did not affect adult survival in either topical or contact residue assays over a wide range of doses. Reproduction also was unaffected at doses up to field application rates. Egg viability, but not rate of oviposition, declined slightly at doses $\geq$5 times higher than field application rates. Results suggest that buprofezin is benign to *G. punctipes* but that pyriproxyfen may be slightly to moderately detrimental under ideal exposure. Similar assays are planned for *Orius tristicolor*, *Collops vittatus* and *Chrysoperla carnea* and further studies with IGRs and other insecticides are planned for all species.

Investigator's Name(s): Steven E. Naranjo.

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Research & Implementation Area: Section C: Chemical Control, Biopesticides, Resistance Management and Application Methods.

Dates Covered by the Report: January 1997 - December 1998

Effect of an Experimental Insecticide (NI-25) on Natural Enemies of Sweetpotato Whitefly

Replicated small-plot studies were continued in 1998 to test the effects of a new imidacloprid-like insecticide (NI-25, Rhone-Poulenc) on generalist predators and whitefly parasitoids in cotton. Treatments consisted of NI-25 at 0.05, 0.075 and 0.1 lb AI/A, pyriproxyfen (grower standard), and an untreated control. Insecticides were applied according to thresholds and natural enemy populations were monitored weekly from May through September. Rates of parasitism were low (< 12%) and there were no differences in percentage parasitism between any of the treatments and the untreated control on any sampling dates. Densities of predatory beetles were generally low and no treatment differences were detected on any sample date. NI-25 significantly depressed populations of predaceous Heteroptera in comparison with the untreated control and pyriproxyfen on several sample dates and a decline in the density of spiders was detected on 1 sample date in July. Overall, these results are consistent with findings in 1997 studies. Heteropteran predators are facultative plant-feeders and this may place them at higher risk for exposure to NI-25 given its systemic activity.

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Research & Implementation Area: Section C: Chemical Control, Biopesticides, Resistance Management and Application Methods.

Dates Covered by the Report: March 1999 - July 1999

Evaluation of Insecticides for Silverleaf Whitefly Control In Spring Planted Cantaloupe Melons, 1999

A stand of cantaloupe melons, var. Topmark, was established at UC Desert Research & Extension Center 24 March 1999. Nine insecticide treatments and an untreated control were replicated four times in a randomized complete design experiment. Insecticide treatments were as follows: Platinum 2 SC applied via drip irrigation at rates of 0.036 and 0.046 lb ai/acre and Admire 2 F was applied through the drip irrigation at 0.25 lb ai/acre, but was not followed by foliar sprays. Admire 2 F was applied through the drip irrigation at 0.25 lb ai/acre followed by various treatments of foliar sprays: Capture 2 EC + Thiodan 3 EC at 0.1 and 1.0 lb ai/acre, Danitol 2.4 EC + Thiodan 3EC at 0.2 and 1.0 lb ai/acre, Applaud 70 WP at 0.25 lb ai/acre, Applaud 70 WP at 0.37 lb ai/acre. Actara 25 WG was applied at 0.047 and 0.086 lb ai/acre and was not proceeded by any drip irrigation insecticide treatments. Drip irrigation insecticides treatments were applied 21 April. Foliar spray insecticide treatments were applied 10 June. Silverleaf whitefly, *Bemisia argentifolii*, were sampled by counting adults on the fourth leaf from the terminal of the main stem cane from ten plants at random in each plot via the leaf turn method and whitefly nymphs were counted on 1.65 cm^2 leaf disks from ten crown leaves extracted from randomly selected melon plants in each plot. Adult silverleaf whitefly and nymphs were sampled on the following dates: 21 & 26 April, 3, 10, 17, 24 May, 1, 7, 15, 21 & 28 June, 1999.

Adult whitefly population levels were suppressed by Platinum 2 SC at 0.036 lb ai/acre for 5 weeks following drip irrigation application. Adult whitefly population levels were suppressed by Platinum 2 SC at 0.046 lb ai/acre and Admire 2 F at 0.25 lb ai/acre for 7 weeks following drip irrigation application. Adult whitefly population levels were not suppressed by foliar insecticide spray applications. Silverleaf whitefly nymphal population levels were suppressed by Platinum 2 SC treatments and by Admire 2 F for 10 weeks following drip irrigation application. Silverleaf whitefly nymphal population levels were suppressed by all foliar treatments for 3 weeks following application.

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Research & Implementation Area: Section C: Chemical Control, Biopesticides, Resistance Management and Application Methods.

Dates Covered by the Report: March 1999 - December 1999

Evaluation of Insecticides for Silverleaf Whitefly Control In Cotton, 1999

A stand of cotton, var. DPL 5415, was established at UC Desert Research & Extension Center 23 March 1999. Eight insecticide treatments and an untreated control were replicated four times in a randomized complete design. Insecticide treatments were as follows: Rimon 10 EC at 0.011, 0.022, and 0.045 lb ai/a applied 15 June, Applaud 70 WP at 0.35 lb ai/a applied 15 June, Danitol 2.4 EC at 0.2 lb al at 0.2 lb ai/a plus Orthene 90S at 0.5 lb ai/a applied 15 June, 14 July and 3 August, Knack 0.86 EC at 0.05 lb ai/a applied 15 June, NI-25 70 WP (Acetamiprid) at 0.044 and 0.1 lb ai/a applied 15 June, 14 July and 3 August Silverleaf whitefly adults were sampled from ten plants at random in each plot via the leaf turn method using the fifth main stem leaf from the terminal on 27 May, 3, 10, 14, 18, 22 & 29 June, 5, 9, 13, 16, 21 & 26 July. Silverleaf whitefly nymphs were counted on 1.65 cm^2 leaf disks from 5th position, main-stem terminal leaves extracted from ten randomly selected plants in each plot on 10, 18, 22 & 29 June, 5, 9, 13, 16, 21 & 26 July. Seed cotton was hand picked from 0.002 acre per plot and yield data were recorded on 8 and 9 September 1999. Seed cotton samples were ginned at the USDA--ARS, Western Cotton Research Laboratory in Phoenix, AZ and lint samples were sent to the USDA--ARS, Cotton Quality Research Station in Clemson, SC for stickiness and sugar analysis.

The seasonal nymphal means for the insect growth regulator (IGR) treatments Rimon 10 EC, Applaud 70 WP and Knack 0.86 EC were not different than the non-treated control. The nymphal means for the IGR treatments Rimon 10 EC, Applaud 70 WP and Knack 0.86 EC were not different than the non-treated control on any of the sampling dates with the exception of Knack 0.86 EC on 26 June, 11-days after treatment. The adult means for the IGR treatments Rimon 10 EC, Applaud 70 WP and Knack 0.86 EC were not different than the non-treated control on any of the sampling dates with the exception of Rimon 10 EC on 18 and Rimon 10 EC, Applaud 70 WP and Knack 0.86 EC on 22 June. The NI-25 70 WP treatments and Danitol + Orthene treatment provided the highest levels of control for silverleaf whitefly nymphs with means lower than the non-treated control on all post-treatment sampling dates, P # 0.05. The NI-25 70 WP treatments and Danitol + Orthene treatments were variable by sampling date for control of silverleaf whitefly adults , but usually did not lower population levels below the non-treated control and the seasonal means for these insecticide treatments were not different from the non-treated control. The means for seed cotton yields for NI-25 70 WP treatments and the Danitol + Orthene treatment were greater than all of the Rimon 10 EC treatments and the non-treated control. The mean for seed cotton yields for Knack 0.86 EC was not different from the Rimon 10 EC treatments and the non-treated control nor from the means for seed cotton yields for NI-25 70 WP treatments and the Danitol + Orthene treatment.

Investigator's Name(s): Eric T. Natwick & Keith S. Mayberry.

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Research & Implementation Area: Section C: Chemical Control, Biopesticides, Resistance Management and Application Methods.

Dates Covered by the Report: September 1999 - January 1999

Efficacy of Selected Insecticides for Silverleaf Whitefly Control in Iceberg Lettuce, 1999

Iceberg lettuce var. Desert Queen was sown at UC Desert Research & Extension Center 16 September 1999. Four insecticide treatments and an untreated control were replicated five times in a randomized complete design experiment. Insecticide treatments were as follows: Admire 2F at 0.25 lb ai/acre injected 3 inches below the seed-line pre-plant, Applaud 70 WP at 0.25 lb ai/acre, Applaud 70 WP at 0.38 lb ai/acre, and Phaser 3 EC at 0.75 lb ai/acre. Foliar sprays were applied on 28 September and 13 October, 1999. Silverleaf whitefly, *Bemisia argentifolii*, were sampled by counting adults via leaf turn of basal leaves on ten plants at random from each plot and nymphs were counted on 1.65 cm^2 of leaf surface from basal leaves of ten plants at random from each plot on 27 September, 4, 12, 18, & 25 October, 1, 8 & 15 November 1999.

The silverleaf whitefly adult means for the non-treated control were not greater than the adult means for any of the insecticide treatments on any of the sampling dates with the exception of Admire 2 F on 1 November. The silverleaf whitefly nymphal seasonal mean for the non-treated control was greater than the Admire 2 F nymphal seasonal mean but was not greater than the nymphal seasonal mean for the other insecticide treatments. The nymphal means for Phaser 3 EC were lower that the means for the non-treated control on 1 and 8 November but not on other sampling dates. The nymphal means for Applaud 70 WP at 0.25 lb ai/acre and Applaud 70 WP at 0.38 lb ai/acre were not lower that the means for the non-treated control on any of the sampling dates.

Investigator's Name(s): N. Prabhaker[1], N. C. Toscano[1], and T. J. Henneberry[2].

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered By the Report: June 1998 - September 1999

Incorporating Various Neonicotinoids into Chemical Control Practices for Whitefly Management

The impending widespread use of various neonicotinoids currently under development has focused attention on the risk of rapid selection of resistance as well as development of cross-resistance in target insects. We have conducted experimental studies that address these two concerns, the cross-resistance patterns between three neonicotinoids, acetamiprid, imidacloprid and thiamethoxam, and the rate of resistance development to thiamethoxam in whiteflies.

Monitoring for baseline susceptibility was the first step in examining the potential problems that might arise in the field with the use of multiple neonicotinoids. In general, monitoring results will provide comparisons among populations that may reveal cross-resistance patterns to acetamiprid, imidacloprid and thiamethoxam. Monitoring results demonstrated trends in whitefly responses from Imperial Valley, CA, to all three neonicotinoids. Seasonal variations in whitefly responses to acetamiprid, imidacloprid and thiamethoxam were observed. Whiteflies showed higher LC_{50}s during summer when collected on cotton compared to lower LC_{50}s during spring and early fall on melons and cole crops. The LC_{50}s ranged from 2.5 to 139 ppm for thiamethoxam and from 4.7 to 80.2 ppm for acetamiprid. Susceptibility appears to decline during late summer and early fall. This trend was observed to other conventional chemistries and suggests the absence of any clear-cut cross-resistance patterns between the three neonicotinoids. Perhaps both biological and environmental factors can affect a pest's response to insecticides.

Cross-resistance patterns to acetamiprid and thiamethoxam against an imidacloprid-resistant strain (IM-R) varied for each compound with time, for example, thiamethoxam was more toxic to the resistant whiteflies than acetamiprid within 48 h (LC_{50} = 10 ppm). Acetamiprid was also active against the IM-R strain but was slower in action compared to the toxicity of thiamethoxam (LC_{50} = 39 ppm in 96 h). Acetamiprid was 10X less active against the IM-R strain in 72 h. This large difference in toxicity between thiamethoxam and acetamiprid is not observed in the field populations suggesting that cross-resistance patterns may not be the same for all populations. The rate and magnitude of resistance development to thiamethoxam was fairly rapid under laboratory conditions. Resistance level was low (7-fold) early in the selection process during the third generation but increased 400-fold by the fifth generation. Although the selection was achieved under laboratory conditions, these results can still be useful predictors of selection effects in the field after widespread use of these three neonicotinoids. In addition, selection of resistant strains in the laboratory allow experimental testing of management tactics to delay resistance to the three neonicotinoids.

Two synergists, DEF and piperonyl butoxide (PB), marginally increased toxicity to thiamethoxam in the Thiam-R strain. The combination of imidacloprid with DEF and PB against the Thiam-R strain showed synergistic activity as indicated by a decrease in LC_{50}s of imidacloprid from 42 ppm to 2.3 ppm with DEF and to 12.8 ppm with PB. The limited effect of the two synergists on thiamethoxam resistance in this strain indicate that this particular resistance might be metabolic. Toxicity was also enhanced to thiamethoxam in the IM-R strain when DEF and PB were applied against the adults. Future work will include metabolism studies to learn the mechanisms of resistance in this strain.

Although the results of this study do not show definite cross-resistance patterns in a number of whitefly populations to the three neonicotinoids, the development of cross-resistance with extensive use is a possibility because of similarity in structure. To preserve the value of this chemistry and to avoid high selection pressure on any one chemical from this group, there is an urgent need for integrating the neonicotinoids into a diversified program of chemical control.

Research Summary

Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods

Compiled by: James Brazzle

The status of silverleaf whitefly as a managed pest in most agricultural cropping systems is largely due to the successful implementation of various chemical control approaches. The continued development and registration of new insecticide chemistries, insect growth regulators and biopesticides provides producers with a number of pest management options for whiteflies. This has allowed industry, government and university scientists to collaboratively develop and refine integrated and resistance management programs within a number of cropping systems. Overall, these efforts have resulted in the reduction and harmonization of chemical use, and a return to economic crop production in the southern and southwestern U.S.

Efforts to improve chemical control were focused on the evaluation of systemic insecticides, insect growth regulators (IGRs) and biopesticides. A significant amount of work was reported on the development of use patterns for the neonicitinoid class of chemistry. Formulations of thiamethoxam and acetamiprid applied as sprays to foliage and injected into the soil appear promising and may provide alternatives to prophylactic uses of imidacloprid in vegetables and melons crops. Use of IGRs remains an important chemical control approach as illustrated by their continued success in desert cotton crops and the development of action thresholds in melons. A considerable amount of work was conducted across disciplines to examine the impacts of several IGRs on whitefly parasitoids and predators. Evaluations of new promising IGR, novaluron (Rimon), in cotton and vegetables was reported for the first time.

Workers continued to evaluate several biopesticides (azidirachtin, and entomopathogenic fungi, *Beauvaria bassiana* and *Paecilomyces fumosoroseus*) for whitefly control and compatibility with natural enemies in integrated management programs. Efforts were continued to refine application methods to increase the efficacy of these biorationals. Work with application methods also focused on improving the delivery of neonicotinoids insecticides via drip irrigation and soil injection, and use of fogging devises for glasshouse crops. Significant progress was made in 1999 to validate an action threshold for Applaud (buprofezin) in melons, and develop a better understanding of the relationship between sticky cotton and whitefly densities.

The present dependence on imidacloprid and the impending widespread use of the various neonicotinoids under development has focused research efforts to identify resistance risks of whiteflies to this class of chemistry. Numerous basic studies focusing on insecticide resistance examined the genetics and biochemistry of resistance and cross-resistance concentrating on the neonicitonoids. In particular, genetic and biochemical studies have been focused on the role of MFO-based metabolism and esterases in resistance to imidacloprid. The metabolic role of synergists DEF and piperonyl butoxide to enhance the toxicity of imidacloprid was also investigated. A significant effort has been made by several laboratories to examine the cross-resistance patterns between three neonicotinoids; acetamiprid, thiamethoxam and imidacloprid. Although no definitive cross-resistance patterns were observed in a number of whitefly populations, the development of cross-resistance with extensive use is a possibility because of similarity in structure. Consequently, in order to avoid high selection pressure on any one chemical from this group, there is an urgent need for integrating the neonicotinoids into a diversified management program.

The development of resistance management programs at the grower level appeared to be minimal in 1999. However, efforts continued in collecting baseline bioassay data on insecticide susceptibility and transferring this information to producers on a regional basis. Within the next few years, scientists and extension workers are confident that based on the above science, integrated programs in numerous cropping systems will be in place that optimizes insecticide, IGR and biopesticde efficacy while minimizing their impacts on biological control efforts.

The successful management of silverleaf whitefly will also be impacted by regulatory changes, in particular "The Food Quality Protection Act". FQPA will have a significant impact on the current and future registrations of key whitefly insecticides and will determine the success of resistance management programs. The impacts of FQPA need to be fully understood as future priorities are set for chemical management of silverleaf whitefly.

Table C. Chemical Control, Biopesticides, Resistance Management, and Application Methods.

Research Approaches[a]	Year 1 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Improve insecticide efficacy:				
Develop, test, and assist in the registration of insecticides, biorationals, and natural products.	Develop new chemistries and natural products. Develop improved techniques for evaluating efficacy of insecticides. Support registration of desirable new products by providing information to regulatory agencies.	X		New studies reported in this area in 1997 = 39. New biopesticides like *Petunia* extract and *Melia* extract tested. New biorationals tested or reported on included benzyl phenal urea napthaphenol and antibiotics (to act against symbiotic bacteria).
Develop improved methods of application including formulation and delivery of materials to improve control.	Develop spray systems for better underleaf coverage. Evaluate rates, timing, placement in relation to efficacy. Consider formulation, UV protectants, and other means to improve efficacy. Develop improved methods to evaluate application efficacy. Field test under commercial conditions for technology transfer.	X		New studies = 10. Thermal fogger evaluated for greenhouse use. However, a comparison of five-sprayers in the field trials showed no significant differences between hydraulic, air-assist and electrostatic technology.
Conserve insecticide efficacy:				
Relate action thresholds to insecticide usage patterns.	Refine action thresholds based on insecticide efficacy and input from other control strategies.	X		New studies = 8. Cost-benefit study of IPM system in cotton. Life table approach to evaluate impact of mortality factors initiated. Training effort to extend threshold information to growers in Arizona.
Elucidate the role of genetic, biochemical and ecological factors leading to insecticide resistance.	Establish whitefly strains resistant and susceptible to various classes of insecticide. Conduct studies to determine the genetics and biochemistry of resistance and cross resistance to different classes of insecticide.	X		New studies = 4. Imidacloprid binding site elucidated. Studies completed on stability of resistance in *Bemisia* including agricultural and ecological factors.

Table C. Chemical Control, Biopesticides, Resistance Management, and Application Methods. (Continued)

Research Approaches[a]	Year 1 Goals Statement	Progress Achieved Yes	No	Significance
Improve insecticide efficacy:				
Improve techniques for monitoring resistance.	Establish baseline data on toxogenic responses of whitefly populations to new insecticides.	X		New studies = 9. Bioassays developed for testing sensitivity to imidacloprid. Baseline data obtained on sensitivity to imidacloprid and IGRs pyriproxyfen and buprofazin.
Develop, evaluate and refine resistance management systems.	Evaluate the effects of mixtures and rotations of new and old chemistries to mitigate selection for resistance.	X		New studies = 14. Area-wide plans for management of resistance refined in Arizona and California. Large-scale trials of resistance management strategies conducted.
Integrate chemical control with other tactics.	Evaluate selectivity of synthetic insecticides and natural products to key whitefly natural enemies.	X		New studies = 10, including laboratory and field studies on compatibility with whitefly natural enemies. Also a study on effects of pyrethroids on anitbiotic factors bred into crops.

[a] See Table A for complementary research on thresholds.
[a] See Table B for complementary research on virus/vector interactions.
[a] See Table D for complementary research on biological control.
[b] See Table E and F for complementary research on systems management.

Table C. Chemical Control, Biopesticides, Resistance Management, and Application Methods.

Research Approaches[a]	Year 2 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Improve insecticide efficacy:				
Develop, test, and assist in the registration of insecticides, biorationals, and natural products.	Determine new modes of action of effective materials. Elucidate biochemical pathways of synthesis and degradation of natural products.	X		(1) Section 3 registration of IGRs. (2) Section 18's supported, acetamiprid summer '99. (3) progress evaluating soil applied modes of action, sugar esters and entomopathic fungi., integration of biorationals and conventional chemistries. Need to evaluate future impact of FQPA. References 40, 69, 71, 78, 81, 103, 104, 108, 145, 165, 166, 167, 168, 180, 186, 187, 188, 212, 220, 262, 263, 273, 274, 297
Develop improved methods of application including formulation and delivery of materials to improve control.	Develop spray systems for better underleaf coverage. Evaluate rates, timing, placement in relation to efficacy. Consider formulation, UV protectants, and other means to improve efficacy. Develop improved methods to evaluate application efficacy. Field test under commercial conditions for technology transfer.	X		Akey's work with high PSI systems, increasing stability for azadiractin and utilizing digital photographs to evaluate application efficacy. References 47, 131, 139
Conserve insecticide efficacy:				
Relate action thresholds to insecticide usage patterns.	Refine action thresholds based on insecticide efficacy and input from other control strategies.	X		Mint sampling plan/thresholds, distribution patterns validated, References 35, 125, 212, 317
Elucidate the role of genetic, biochemical and ecological factors leading to insecticide resistance.	Establish whitefly strains resistant and susceptible to various classes of insecticide. Conduct studies to determine the genetics and biochemistry of resistance and cross resistance to different classes of insecticide. Evaluate the role of refuge habitats (weeds, tolerant crops, urban areas) to assure input of susceptible genes in whitefly population.	X		Resistant colonies exist to endosulfan, chlorpyrifos, imidacloprid, bifenthrin; genetic and biochemistry studies are concentrated on acetylcholinesterase (Byrne) and nicotinyls; cross resistance being studied between nicotinyls and neonicotinyls. Impact of ecological factors such as nutrition, host plant response, local cropping patterns are being studied. Role of alfalfa as a refuge has been evaluated. References 18, 22, 46,

Table C. Chemical Control, Biopesticides, Resistance Management, and Application Methods. (Continued)

Research Approaches[a]	Year 2 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Improve insecticide efficacy:				
Improve techniques for monitoring resistance.	Establish baseline data on toxogenic responses of whitefly populations to new insecticides. Expand comparative studies of resistance levels in diverse agro-ecosystems. Evaluate relationship between monitoring results and field efficacy.	X		Baselines have and are being established for IGRs and systemic insecticides. Work in Cal. & Arizona ongoing to evaluate regional resistance management techniques which include four distinct agro-ecosystems. Work in ornamentals is increasing. Relationships between monitoring results and field failure are primarily anecdotal at this time. References 140, 227, 286, 314
Develop, evaluate and refine resistance management systems.	Evaluate the effects of mixtures and rotations of new and old chemistries to mitigate selection for resistance. Develop methods to evaluate and augment the beneficial influence of refuges as sources of susceptible genes to the population pool.	X		Prabhaker et al. in press. Studies to increase horizontal integration of resistance management programs are addressing influence of refuges in diverse agro-ecosystems. References 20, 47, 76, 77, 235, 245, 284, 310
Integrate chemical control with other tactics.	Evaluate selectivity of synthetic insecticides and natural products to key whitefly natural enemies. Test compatibility of biological control with selective synthetic or natural product insecticides as required.	X		Most efficacy trials include a compatibility evaluation, selectivity evaluations include systemics, entomopathic fungi; life tables are contributing to our understanding here. References 7, 9, 10, 11, 13, 24, 25, 27, 31, 32, 37, 38, 49, 70, 89, 90, 93, 96, 97, 98, 105, 110, 129, 147, 149, 153, 160, 169, 174, 194, 200, 247

[a] See Table A for complementary research on thresholds.
[a] See Table B for complementary research on virus/vector interactions.
[a] See Table D for complementary research on biological control.
[b] See Table E and F for complementary research on systems management.

Table C. Chemical Control, Biopesticides, Resistance Management, and Application Methods.

Research Approaches[a]	Year 3 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Improve insecticide efficacy:				
Develop, test, and assist in the registration of insecticides, biorationals, and natural products.	Develop new chemistries and natural products. Develop improved techniques for evaluating efficacy of insecticides. Support registration of desirable new products by providing information to regulatory agencies. Determine new modes of action of effective materials. Elucidate biochemical pathways of synthesis and degradation of natural products. Same as Year 2. Evaluate the potential for transforming plants with natural product genes.	X		Section 3 registration of IGRs & Admire in additional crops, Section 18's supported, work with Rimon a new IGR, continued work with neonicotinyls as soil and foliar applications, sugar esters, azadirachtins and entomopathic fungi, toxicity of abamectin, tebufenozide, chlorfenpyr & pymetrozine evaluated, integration of biorationals and conventional chemistries, work on products that induce resistance has some promise, sampling plan in cantaloupes, life table studies, evaluated the impacts of FQPA References: 59, 60, 83, 145, 164, 167, 183, 184, 189, 192, 210, 214, 252 Tomato transformations – Florida.
Develop improved methods of application including formulation and delivery of materials to improve control.	Develop spray systems for better underleaf coverage. Evaluate rates, timing, placement in relation to efficacy. Consider formulation, UV protectants, and other means to improve efficacy. Develop improved methods to evaluate application efficacy. Field test under commercial conditions for technology transfer. Same as Year 2	X		Additional work with swivel nozzles, several commercial studies examining drip and at planting methods of application, ultrasonic fogging devices for greenhouses, application methods to improve efficacy of entomopathic fungi, the use of DEF & PBO to enhance efficacy and overcome resistance. References: 76, 77, 244,
Conserve insecticide efficacy:				
Relate action thresholds to insecticide usage patterns.	Refine action thresholds based on insecticide efficacy and input from other control strategies Same as Year 2	X		Continued work on sticky cotton sampling plan, development of IGR specific action thresholds in melons, Yield, sticky cotton – whitefly relationships studied. References: 18, 95, 182

Table C. Chemical Control, Biopesticides, Resistance Management, and Application Methods. (Continued)

Research Approaches[a]	Year 3 Goals Statement	Progress Achieved Yes	No	Significance
Elucidate the role of genetic, biochemical and ecological factors leading to insecticide resistance.	Conduct studies to determine the genetics and biochemistry of resistance and cross resistance to different classes of insecticide. Evaluate the role of refuge habitats (weeds, tolerant crops, urban areas) to assure input of susceptible genes in whitefly population. Evaluate the influence of host plant on susceptibility to insecticides.	X		Genetic and biochemistry studies are concentrated on the role of MFO-based metabolism and esterases in resistance to nicotinyls and bifenthrin; cross resistance being studied with nicotinyls and neonicotinyls. Impact of ecological factors such as nutrition, host plant response, local cropping patterns are being studied. Role of alfalfa as a refuge has been evaluated. Host plant influence on efficacy has been evaluated based on seasonality, external & internal uptake, changes in metabolites and several compounds screened on various host plants. References: 12, 128, 185, 220
Improve insecticide efficacy:				
Improve techniques for monitoring resistance.	Establish baseline data on toxogenic responses of whitefly populations to new insecticides. Same as Year 1. Expand comparative studies of resistance levels in diverse agro-ecosystems. Evaluate relationship between monitoring results and field efficacy. Same as Year 2. Summarize, analyze, and produce standardized comparable monitoring systems.	X		Baselines have and are being established for IGRs and systemic insecticides. Work in Cal. & Arizona are evaluating regional resistance management techniques which include four distinct agro-ecosystems. Work in ornamentals is increasing. Relationships between monitoring results and field failure are primarily anecdotal at this time. References: 73, 74, 75

Table C. Chemical Control, Biopesticides, Resistance Management, and Application Methods. (Continued)

Research Approaches[a]	Year 3 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Develop, evaluate and refine resistance management systems.	Evaluate the effects of mixtures and rotations of new and old chemistries to mitigate selection for resistance. Same as Year 1. Develop methods to evaluate and augment the beneficial influence of refuges as sources of susceptible genes to the population pool. Same as Year 2. Develop criteria for integration of successful strategies in agricultural systems. Field test resistance management systems as long range components of successful IPM.	X		Prabhaker et al. in press. Studies to increase horizontal integration of resistance management programs are addressing influence of refuges in diverse agro-ecosystems. Areawide resistance management programs in place in Cal. and Arizona.
Integrate chemical control with other tactics.	Evaluate selectivity of synthetic insecticides and natural products to key whitefly natural enemies. Same as Year 1. Test compatibility of biological control with selective synthetic or natural product insecticides as required. Same as Year 2. Integrate systems with host plant resistance and cultural controls	X		Most efficacy trials include a compatibility evaluation, selectivity evaluations include IGR's, neonicotinyls, entomopathic fungi; life tables are contributing to our understanding here. Integration of smooth leaf varieties of cotton with chemical control being practiced.

[a] See Table A for complementary research on thresholds.
[a] See Table B for complementary research on virus/vector interactions.
[a] See Table D for complementary research on biological control.
[b] See Table E and F for complementary research on systems management.

Section D: Natural Enemy Ecology and Biological Control
Co-Chairs: James Hagler and Matt Ciomperlik

Investigator's Names: D. H. Akey and T. J. Henneberry.

Affiliation & Location: USDA, ARS, Western Cotton Research Laboratory, Phoenix AZ 85040-8803.

Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control.

Dates Covered by the Report: June-September 1999

Effect on Beneficial Arthropods of Biorationals (Insect Growth Regulators and Entomopathogenic Fungi) Used for Control of Silverleaf Whitefly, *Bemisia argentifolii*, in Upland Cotton in Arizona

Deltapine NuCOTN 33^B was planted and furrow irrigated in plots 109 ft. in length and 12 rows across (40-in. rows). Plots were separated by 2-fallow rows and 20 ft. alleys. Spray applications were made by a ground boom with 5 nozzles/row, 1 overhead, and 2 swivel nozzles angled upward on a drop on each side of the row, at 250 psi and 30 gal/ac. Eight sprays were applied weekly beginning July 22 and ending September 9. The 1999 cotton season was a good year in respect to abiotic factors favorable to growing cotton. Silverleaf whitefly populations were present in cotton from mid to late season.

Biorational entomopathogenic fungi used included: *Beauveria bassiana,* as Naturalis® L, Troy Biosciences Inc. at 10 oz. product/ac, 2.3x 10^7 conidia/ml, as Mycotrol® ES, Mycotech Corp., 0.5 pt/ac, 2 x 10^{13} spores/qt, and *Paecilomyces fumosoroseus* PFR- 97™ Thermo Trilogy Corp., 0.025 lbs. / gal., 1x 10^9 CFU (spores)/ gm equivalent 20% product. All three of these products were used at full rate for multiple applications. Biorational insect growth regulators used were at full rate as single or multiple applications and included: azadirachtin as Bollwhip™ (Thermo Trilogy Corp.), 4.5% formulation 6 oz product /ac.(note, other action modes also); buprofezin as Applaud™ 70 WP (AgrEvo), 0.35 lb. AI/ac; and pyriproxyfen as Knack™ 0.86 EC (Valent USA) 0.054 lb. AI/ac. These treatments were part of a 10-treatment random block design that included a "Best Agricultural Practice" (BAP) treatment, and an embedded-control treatment, plus a single 1-ac block control. Treatment efficacy was measured as mean percent reduction from the block control. Weekly sweeps (25/plot) were taken in all plots for predators, parasites, the thrip, *Frankliniella occidentali*, and *Lygus* (primarily *hesperus, Lygus* reported elsewhere in this review). Treatment efficacy was measured as mean percent reduction (%) from the block control; statistically significant = s, and statistically insignificant = **ns**, by ANOVA with P< 0.05 or stated otherwise.

Efficacies of biorational-entomopathogenic fungi were as follows for Naturalis® L, Mycotrol® ES, and PFR- 97™, respectively, on populations of: *Frankliniella occidentalis, Drapetis,* and *Orius*, 0% for all; *Chrysoperla* larvae, 0, 23, and 0%, *Collops*, 39, 39, and 22%; *Pseudatomoscelis*, 8, 16, and 14%; *Spanagonicus,* 80, 40, and 0%; (all **ns**,). Naturalis® L, Mycotrol® ES had efficacies on populations of *Geocoris* of 16 and 17% (**ns**); in contrast, PFR- 97™ had an efficacy of 26% (**s**, P< 0.001). Mycotrol® ES had an efficacy on populations of *Hippodamia* of 60% (**ns**); in contrast, Naturalis® L and PFR-97™ had efficacies of 80 and 100% (**s**). On misc. spiders, Naturalis® L, Mycotrol® ES, and PFR- 97™ had efficacies of 28, 33, and 22 % (**s**). Efficacies of biorational insect growth regulators were as follows, respectively: 1) Bollwhip™ -- 0 % on *Drapetis, Frankliniella occidentalis, Orius,* and *Spanagonicus* populations (**ns**), 39 and 19% on *Collops* and *Pseudatomoscelis* populations (**ns**), 23, 22, and 99% on *Chrysoperla* larvae, misc. spiders, and *Hippodamia* populations (**s**), and 22% on *Geocoris* populations (**s**, P<0.001); 2) Applaud™-- 0% on *Chrysoperla* larvae, *Drapetis, Frankliniella occidentalis, Geocoris, Hippodamia, Orius*, and *Spanagonicus* populations (**ns**), 63, 22 and 2% on *Collops,* misc. spiders and *Pseudatomoscelis* populations(**ns**); and 3) Knack™-- 0% on *Chrysoperla* larvae, *Collops, Frankliniella occidentalis,* misc. spiders and *Pseudatomoscelis* populations(**ns**), 23, 12, and 26% on *Drapetis, Geocoris, Orius,* populations (**ns**), 100 and 80% on *Hippodamia* and *Spanagonicus* populations(**s**, P<0.01 and 0.02).

Investigator's Name(s): D. H. Akey and T. J. Henneberry.

Affiliation & Location: USDA, ARS, Western Cotton Research Laboratory, Phoenix, AZ 85040-8803.

Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control.

Dates Covered by the Report: June-September 1999

Use of the Entomopathogenic Fungi, *Beauveria bassiana*, and *Paecilomyces fumosoroseus* as Biorational Agents Against the Silverleaf Whitefly, *Bemisia argentifolii*, in Field Trials in Upland Cotton

Deltapine NuCOTN 33^{B} was planted and furrow irrigated in plots 109 ft. in length and 12 rows across (40-in. rows). Plots were separated by 2 fallow rows and 20 ft. alleys. Spray applications were made by a ground boom with 5 nozzles/row, 1 overhead, and 2 swivel nozzles angled upward on a drop on each side of the row, at 250 psi and 30 gal/ac. Eight sprays were applied weekly beginning July 22 and ending September 9. The 1999 cotton season was a good year in respect to abiotic factors favorable to growing cotton. Silverleaf whitefly populations were present in cotton from mid to late season.

Biorational entomopathogenic fungi used included: *Beauveria bassiana,* as Naturalis® L, Troy Biosciences Inc. at 10 oz. product/ac, 2.3x 10^{7} conidia/ml, as Mycotrol® ES, Mycotech Corp., 0.5 pt/ac, 2 x 10^{13} spores/qt, and *Paecilomyces fumosoroseus* PFR- 97™ Thermo Trilogy Corp., 0.025 lb/gal, 1x 10^{9} CFU (spores)/gm equivalent 20% product. All three of these products were used at full rate for multiple applications. These treatments were part of a 10-treatment random block design that included a "Best Agricultural Practice" (BAP) regime and an embedded-control treatment, plus a single 1-ac block control.

Whitefly eggs, small nymphs, and large nymphs were sampled from one leaf taken from each of 10 plants per plot, from the 5th main-stem node down from the 1st expanded terminal leaf. Each sample was counted from a 2.22 cm diameter disk taken from the leaf between the main (central) and the adjacent lateral vein. All whitefly adults were counted on the 5th main-stem leaf abaxial surface sampled from 30 leaves/plot, using the leaf turn method; the first 10 were from the same plants used for immature samples.

Efficacies, of *Beauveria bassiana* as Mycotrol® ES and Naturalis® L respectively, were as follows: 26 and 41% against eggs; 23 and 46% against small nymphs; and 56 and 74% against large nymphs. Efficacies of *P. fumosoroseus* as PFR -97™ were as follows: 50% against eggs ; 49% against small nymphs; and 78% against large nymphs. Compared to the block control, the efficacies of all 3 entomopathogenic fungi were significant at $P<0.01$ by ANOVA and ($P<0.05$) by LSD.

Investigator's Name(s): Earl Andress[1], Juli Gould[2], & Mark A. Quinn[3].

Affiliation & Location: USDA--APHIS, Phoenix Plant Protection Center, Brawley CA[1], Phoenix AZ[2], Washington State University, Pullman WA[3].

Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control.

Dates Covered by the Report: September 1999 - January 2000

Assessing the Impact of Established Whitefly Parasitoids in the Imperial Valley Using Multivariate Techniques

Releases of introduced natural enemies of silverleaf whitely have been conducted in the Imperial Valley for several years. Trapping surveys indicate that whitefly populations in the Imperial Valley have been declining for the last four years. Although numerous parasitoids of the introduced species have been recovered, it is not known how much of this overall reduction in whitefly population is due to their effect. In order to assign the portion of this decline that is caused by introduced natural enemies, we have begun a program using a multivariate approach.

Whiteflies and their parasitoids were sampled from broccoli fields during the fall and winter of 1999-2000. Whitefly density and percent parasitism were compared among fields sampled. Crops and land use surrounding the sampled fields were factored into the analysis, and the effects of surrounding crops, land use, indigenous parasitoids, and exotic parasitoids separated. Preliminary results will be presented.

Investigator's Name(s): James S. Buckner[1], Tadeusz J. Poprawski[2], Walker A. Jones[2], & Dennis R. Nelson[1].

Affiliation & Location: [1]USDA--ARS, Biosciences Research Laboratory, Fargo, ND; [2]USDA--ARS, Subtropical Agricultural Research Center, Weslaco, TX.

Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control.

Dates Covered by the Report: 1999

The Effects of *Eretmocerus mundus* Parasitism on the Cuticular Lipids of *Bemisia argentifolii* Nymphs

The cuticular lipid composition of *Bemisia argentifolii* Bellows and Perring (Homoptera: Aleyrodidae) nymphs parasitized by *Eretmocerus mundus* Mercet was determined by capillary gas chromatography (CGC) and CGC-mass spectrometry (CGC-MS) and the results compared with the cuticular lipids of unparasitized nymphs and those nymphs parasitized by *Encarsia pergandiella* Howard. Previous studies with *B. argentifolii* nymphs had shown that wax esters were the major components of the cuticular lipids with lesser amounts of hydrocarbons, long-chain aldehydes and long-chain alcohols.

As compared to unparasitized controls, no appreciable changes in lipid composition were observed for the cuticular lipids of *E. pergandiella*-parasitized nymphs. However, the cuticular lipids from nymphs parasitized by *E. mundus* contained measurable quantities of two additional components in their hydrocarbon fraction. CGC-MS analyses and comparisons with an authentic standard indicated that the two hydrocarbons were the monomethyl-branched alkanes, 2-methyltriacontane (31 carbons) and 2-methyldotriacontane (33 carbons). The occurrences, mechanisms for biosynthesis and possible functions of 2-methylalkanes as cuticular lipid components of insects have been reviewed. Current studies are focusing on determining the site of synthesis of these methyl-branched alkanes and their possible function as chemical cues for host recognition, acceptance and discrimination by *E. mundus* and other whitefly parasitoids.

Investigator's Name(s): D. R. Ellis[1], R. J. McAvoy[1], L. Abu Ayyash[1], M. Flanagan[1], & M. A. Ciomperlik[2].

Affiliation & Location: [1]Department of Plant Science, University of Connecticut, Storrs, CT and [2]USDA--APHIS--PPQ, Mission Plant Protection Center, Mission, TX.

Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control.

Dates Covered by the Report: August - December 1997

Evaluation of *Serangium Parcesetosum* (Coleoptera: Coccinellidae) for Biological Control of Silverleaf Whitefly, *Bemisia Argentifolii* (Homoptera: Aleyrodidae), on Poinsettia.

Silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring, is the major insect pest on greenhouse poinsettia but biological agents capable of suppressing silverleaf whitefly (SLWF) to acceptable levels have been elusive. *Serangium parcesetosum* Sicard is a coccinellid predator that appears to have great potential for SLWF control. In this study, the population dynamics of *B. argentifolii* on caged poinsettias (Euphorbia pulcherrima Wild. var. 'Freedom Red') in response to *Serangium* were characterized. SLWF were introduced to caged poinsettias at rates of 1 or 10 adults per plant, and 6 weeks later, *Serangium* were introduced at rates of 0, 2 or 4 adults per plant. SLWF and *Serangium* populations were monitored weekly during the study.

SLWF mortality increased dramatically within 2 weeks of a single *Serangium* release, and SLWF densities remained at or near the levels observed at time of predator introduction for the ensuing 10-week study period. Serangium larvae were observed 2 weeks after adults were released in cages with high initial SLWF levels but not in cages with low initial SLWF. With high initial SLWF, *Serangium* larvae were recovered as late as 10 weeks after predator introduction. It appears that SLWF control was primarily due to the prolonged survival and continuous feeding of individual beetles. Our data suggest that *Serangium* may be a good candidate for inclusion in an interspecific biological control approach to SLWF management on greenhouse poinsettia.

Investigator's Name(s): Juli Gould & Paul Merten.

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Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control.

Dates Covered by the Report: January 1 - November 30, 1999

Comparison of Four Methods of Releasing Whitefly Parasitoids: Emergence, Survival, Dispersal, and Mating Success

Releasing whitefly parasitoids in field corps is somewhat more complex than releasing them in greenhouse situations. In the field, parasitoids are subjected to higher temperatures, greater temperature fluctuations, wind, rain, low humidity and other factors that are more controlled and constant in greenhouse settings. Once released, successful parasitoids must emerge from the pupal case (if released as pupae), locate each other for mating, and disperse sufficiently throughout the field so that they can find their host. Several methods have been proposed and used to release parasitoids in field crops, with varying success. The goal of our research was to quantify the differences in emergence, survival, dispersal and mating success among four release methods. We also quantified the cost of each release method to determine efficiency.

Parasitoids were released two times in melons (early June and late June) and two times in cotton (early August and late August). Method 1 was to release adult parasitoids, Method 2 was to release parasitoid pupae in gel-caps stuck to the bottom of leaves, Method 3 was to release parasitoid pupae in a paper cup on a wooden skewer and Method 4 simulated releasing parasitoid pupae mixed with vermiculite from a commercial drop-box.

We released parasitoids at rates of 40,000 per acre in ¼ acre plots. We therefore released 10,000 parasitoids per plot. The parasitoids were released in patterns that simulated that which was typical for that method. Adults were released at the center of each of the four quadrants (2,500 per quadrant), gel-caps were placed at the center of each quadrant, the paper cups were placed at the center of the plot (10,000 parasitoids per cup), and the vermiculite was dropped from a 2.5 ml spoon every 1.5 m on every other row throughout the entire plot. Samples were taken from each of 25 points in a 5 by 5 grid throughout each plot. Three days after parasitoid release we vacuumed the foliage around each point for two minutes. We counted the number of parasitoids captured at each point. Each female was dissected and we mounted and cleared the spermatheca to determine whether or not it contained sperm (evidence of mating). Parasitoid emergence was estimated two times per crop in a separate experiment with 30 replicates for each crop. We tested vermiculite that was dropped in the sun and the shade of the plant canopy separately.

Emergence: For three out of the four trials, percentage emergence was higher for the paper cup and gel-cap methods than for the vermiculite. In all four trials, percentage emergence in the vermiculite was greater in the shade than in the sun. Percentage survival of adults was highly variable and more likely reflected mortality due to aspiration than to mortality in the field since the adults could disperse immediately after release.

Survival: Significantly more parasitoids were recovered in the paper-cup plots than in the adult or drop-box plots. There were no significant differences among the gel-cap, adult, or drop-box methods.

Dispersion: In melons, the dispersion of the parasitoids throughout the plot was best for the gel-cap and adult release methods, but in cotton the parasitoids were dispersed throughout the plot well for all four methods.

Mating Success: All but two of the parasitoids we recovered were mated, and there were no significant differences in mating success by release method.

Cost: The cost of treating a 40 acre field was estimated to be $210 for adult release, $123 for the gel-cap method, $53 for the paper cup method, and $636 for the drop-box method.

We would recommend the paper-cup method be used, especially in cotton where we saw a relatively even dispersion after release. We recovered significantly more parasitoids when paper cups were used for release, all recovered females were mated, and the cost was much lower for this method.

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Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control.

Dates Covered by the Report: 1999

Comparison of Functional Response and Mutual Interference Between Two Aphelinid Parasitoids of *Bemisia argentifolii* (Homoptera: Aleyrodidae)

We compared functional responses and mutual interference in an indigenous parasitoid, *Encarsia pergandiella* Howard, with that of an exotic parasitoid, *Eretmocerus mundus* Mercet from Spain, attacking the silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring. Over the experimental host densities tested, *E. mundus* was characterized as a Type 1 response, in contrast to the asymptotic Type II in *E. pergandiella.* The instantaneous attack rates (a') between *E. pergandiella* and *E. mundus* were not significantly different (0.27 vs 0.18 per day, respectively). However, the handling time of *E. pergandiella* (0.05 d or 72 min) was significantly higher than that of *E. mundus* (0.0083 d or 12 min). The higher attack rate of *E. mundus* is largely attributable to its shorter handling times. The mutual interference coefficient *m* of *E. mundus* was numerically, but not statistically higher than that for *E. pergandiella* (0.238 versus 0.184, respectively). Although there were no significant differences in *m*, the comparison raises the interesting question of whether parasitoids with higher attack rates may also have higher levels of mutual interference under conditions of high parasitoid density (e.g. mass rearing).

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Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control.

Dates Covered by the Report: 1999

Temperature Effects on Host Mortality and Parasitoid Survival

The effects of temperature on insect life history was studied for two whitefly hosts, the silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring, and the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), as well as the parasitoid, *Eretmocerus eremicus Rose* & Zolnerowich (Hymenoptera: Aphelinidae) attacking both hosts. Mean egg number as a function of time was fitted to models for age-specific oviposition for each whitefly. In *B. argentifolii,* numbers of eggs increased with time at 15, 21, and 24° C. At 28 and 32° C, the curve declined after 6d, although the model fit was poor. The model did not fit the oviposition data at 32° C. The maximal oviposition rate occurred at 24° C (12 eggs/48-h period), and the model was almost linear. In *T. vaporariorum,* the model closely fitted mean eggs laid, with the highest rate of 12 eggs/48-h at 21 and 24° C. Numbers of whitefly eggs as a function of time and temperature were described by a 3-dimensional surface model which was also used to estimate temperature thresholds for oviposition (12.5° C in *B. argentifolii* and 10.9° C in *T. vaporariorum).* Increasing temperatures produced decreased preoviposition periods in *B. argentifolii,* whereas temperature extremes resulted in longer preovipositional periods in *T. vaporariorum.* Development times from egg to adult, percentage mortality, and estimated degree days for development were measured at 15, 21, 24, 28, and 32° C for both whiteflies, and for *E. eremicus* reared on both hosts. Development rate was higher for *B. argentifolii* than *T. vaporariorum* at 24 and 28° C. Development of *E. eremicus* was higher when *B. argentifolii* was used as the host than *T. vaporariorum* at 24, 28, and 32° C. By extrapolation of development rates, lower developmental thresholds (° C) were estimated as follows: *T. vaporariorum,* 2.92; *B. argentifolii,* 10.32, *E. eremicus on T. vaporariorum,* 5.44; and *E. eremicus on B. argentifolii,* 8.7. Mean degree-day requirements for egg to adult development were calculated at *T. vaporariorum* (483.4); *B. argentifolii* (319.7); *E. eremicus on T. vaporariorum* (417.3); and *E. eremicus on B. argentifolii* (314.4). Percentage mortality also was significantly affected by temperature in both species of whitefly. In *T. vaporariorum,* higher temperatures caused higher levels of mortality, with almost 98% killed at 32° C. The reverse occurred in *B. argentifolii,* where highest levels of mortality were found at the lowest temperatures. Mortality patterns in *E. eremicus* reflected those of the host: increasing with temperature on *T. vaporariorum,* decreasing on *B. argentifolii.* The life history of *E. eremicus* was profoundly affected by that of its host.

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Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control

Dates Covered by the Report: 1999

Tritrophic Interactions Between Two Species of Whiteflies and Two Species of *Eretmocerus* (Hymenoptera: Aphelinidae) on Tomato

Laboratory experiments were conducted to determine the tritrophic interactions of two whitefly species, *Bemisia argentifolii* Bellows & Perring and *Trialeurodes vaporariorum* (Westwood) and two species of parasitoids, *Eretmocerus eremicus* Rose & Zolnerowich (a native species), and *E. mundus* Mercet (an exotic species) on tomato ('Trust' and 'Floridade'). Tomato varieties did not have any significant impacts on whiteflies and their parasitoids. Natural mortality, developmental time, oviposition and progeny between *B. argentifolii T. vaporariorum* were not significant different. The two species of *Eretmocerus* responded differently to the host whitefly species. *E. mundus* developed faster, parasitized more nymphs, had more progeny, had greater parasitism and emergence rate on *B. argentifolii* than on *T. vaporariorum*; whereas E. eremicus performed similarly on either host species with one exception that its females parasitized more *B. argentifolii* nymphs than *T. vaporariorum* nymphs. The females of both parasitoid species emerged from *T. vaporariorum* were significantly larger than that from *B. argentifolii*. The data of this study increased our knowledge of tritrophic interactions of whiteflies-parasitoids-host plants, and the information can be useful for development rearing strategies of whitefly parasitoids, and biological control of the two species of whiteflies using *Eretmocerus*.

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Research & Implementation Area: Section D, Natural Enemy Ecology and Biological Control

Dates Covered by the Report: 1999

Development of *Encarsia formosa* in the Silverleaf Whitefly, *Bemisia argentifolii*: Effect of Host Age

The effect of host age (at the time of parasitization) on the growth and development of *Encarsia formosa* was studied. *E. formosa* was able to parasitize and complete its life cycle in all four instars of the silverleaf whitefly. Parasitoid development was significantly slower when 1st instar hosts were parasitized than when 2nd, 3rd or 4th instars were parasitized. The whitefly instar parasitized had no significant effect on the day in which *E. formosa* larval hatch was first observed, i.e., on the 3rd day post-oviposition. However, mean embryonic development was significantly longer (5 days) when 1st instar hosts were parasitized than when 3rd or 4th instar hosts were parasitized (3.4 and 3.5 days, respectively). The duration of the 1st instar parasitoid was also significantly greater when 1st instar hosts were parasitized (approximately 3 days) than when older host instars were parasitized (approximately 2 days). However, durations of the parasitoid 2nd and 3rd instars and pupa were slightly, but not significantly, longer in hosts parasitized as 1st instars than in hosts parasitized as 2nd, 3rd or 4th instars. Interestingly, no matter which instar was parasitized, the parasitoid did not molt to the 3rd instar until the host had reached stage 4-5 (depth 0.25 mm) of its last instar. It appears, then, that the parasitoid's molt to its last instar depends upon some aspect of host physiology associated with the 4th-5th stage of the whitefly last instar. However, attainment of the 4th-5th stage did not necessarily trigger the parasitoid's final larval molt. Although host instar parasitized had a significant effect on various aspects of parasitoid development, it did not significantly influence the mean size of the parasitoid larva, pupa, or adult. Nor did it significantly affect percent emergence rate or adult longevity. Larval length and adult head width were similar for all parasitoids, regardless of which host instar was parasitized, and percent parasitoid emergence and longevity of adults, while slightly greater for parasitoids developing in hosts parasitized as 3rd or 4th instars than those parasitized as 1st or 2nd instars, was not significantly different. Finally, adult parasitoid emergence was more synchronous when 2nd, 3rd and 4th instar whiteflies were parasitized than when 1st instars were parasitized.

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Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control.

Dates Covered by the Report: Jan-Dec, 1999

Effect of Certain Nutrients on Germination of Whitefly Pathogen Spores

The silverleaf whitefly is susceptible to fatal infection by entomopathogenic fungi such as *Beauveria bassiana* and *Paecilomyces fumosoroseus*. *B. bassiana* rarely occurs naturally in *Bemisia* populations, but it has been used successfully as a mycoinsecticide. Naturally occurring *P. fumosoroseus* has been seen to cause epizootics in localized *Bemisia* populations. Although the general biology of these fungi is well studied, we are always looking for ways to improve control, and a better understanding of the infection process might help accomplish this goal. The main infective propagule for these fungi are spores – usually conidia. Spores germinate on the insect cuticle and then penetrate into the hemoceol where they cause infection. We tested whether sugars (as might occur in association with *Bemisia*) increase spore germination rates. Spores do not germinate in water, and we found that the addition of simple sugars (sucrose, melezitose, and trehalose) had little effect on germination. These sugars stimulated <20% germination of *B. bassiana*, and ≤1% germination of *P. fumosoroseus*, even after 18 hr. On the other hand, an exogenous source of protein (peptone or yeast extract) stimulated 95-100% germination for both fungi. Although it is clear that an exogenous source of carbon is not important to spore germination, sugars might still play a role in fungal growth and infectivity once the spores have germinated.

To see if lack of germination was limiting *B. bassiana* infections in whitefly nymphs, we applied germinated spores to early 3rd instars. Germinating *B. bassiana* conidiospores before applying them to whitefly nymphs increased mortality levels as by as much as 245%. At a concentration where fresh spores caused only 12% mortality (37 spores/mm^2), germinated spores caused 41%. Where fresh spores killed 45% (144 spores/mm^2), germinated spores caused 65% mortality. Spores were germinated using yeast extract, but adding yeast extract without pre-germinating the spores had no effect on whitefly mortality levels. Not only were levels of mortality increased, but the rate of mortality was increased, and this effect was statistically significant. When fresh spores were used, the mean time to death of infected insects was 5.45 (SE=0.16) d for an application rate of 37 spores/mm^2, and 4.74 (SE=0.08) d when applied at 144 spore/mm^2. When the spores were germinated before application, the mean time to death dropped to 4.58 (SE=0.16) and 4.45 (SE=0.10) d for each rate, respectively. Thus, the greatest effect of pre-germinating spores was seen at the lower dose. Perhaps the reason such high doses of spores are needed in field applications of *B. bassiana* is because only a small percentage are germinating on whitefly cuticle.

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Research & Implementation Area: Section D. Natural Enemy Ecology and Biological Control.

Dates Covered by the Report: 1999

Managing *Bemisia argentifolii* Using Mycotrol and Naturalis-L (*Beauveria bassiana*) on Vegetables, Cotton and Ornamentals in Southern United States

Two different strains of *Beauveria bassiana* (Balsamo) Vuillemin, formulated as Mycotrol® and Naturalis-L®, were tested against *Bemisia argentifolii* Bellows & Perring in Arizona, California, Florida, and Texas. Laboratory bioassays, greenhouse and field experiments were conducted on hibiscus, sweetpotato, cantaloupe, cucumber, tomato, eggplants and cotton. Mycotrol caused 76-94% mortality of *B. argentifolii* nymphs under laboratory and greenhouse conditions, where relative humidity was maintained above 90%. In Arizona, on subsurface drip irrigated cantaloupe that was under moderate to light whitefly pressure, Mycotrol provided significant control of whitefly with 68_79% population reduction, whereas Naturalis-L did not. After 3 applications at the labeled rate (1.12 kg/ha), Mycotrol had the cumulative effect of maintaining adult whitefly populations below the economic threshold of 3 per leaf for 28 d after the initial treatment. In the Imperial Valley, California, on cotton and in southwest Florida on field tomato and eggplant, multiple applications of Mycotrol at weekly intervals did not reduce whitefly population compared with untreated control. Naturalis-L was effective against *B. argentifolii* under laboratory conditions, and provided fairly good control on cotton in southern Texas, but did not give sufficient control on cucumber in south Texas or on cantaloupe in Arizona. It appears that applications of *B. bassiana* products, i.e. Mycotrol and Naturalis-L, could play a role in whitefly management, although their usefulness may be limited to high humidity conditions and complete spray coverage.

Investigator's Name(s): G. S. McCutcheon[1] & A. M. Simmons[2].

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Research & Implementation Area: Section D: Natural Enemy Ecology, and Biological Control.

Dates Covered by the Report: 1999

Influence of Temperature on Parasitism by an Indigenous *Eretmocerus* Species

The influence of temperature on rate of parasitism by an indigenous parasitoid, *Eretmocerus* sp., on the whitefly *Bemisia argentifolii* Bellows & Perring was examined in the laboratory. The taxonomic status of the parasitoid is under study by M. Rose. The study was conducted using a range of constant temperatures (20, 25, 30, 35, 40, and 45°C) while maintaining relative humidity at about 80%. The insects were reared on collard plants. Treatments were replicated at each temperature from 4 to 8 times in each of eight trials. The parasitoids were confined on whitefly-infested leaves for 12 hours. Host density was 30 to 40 whitefly nymphs per test arena. There was an increased rate of parasitism by *Eretmocerus* sp. at temperatures above 20°and below 40°C. The relationship between temperature and percentage parasitism was linear when the 40°C treatment was not included in data analysis. Rate of parasitism was highest between 25 and 35°C. At 45°C, the adult parasitoids did not survive during the 12 h oviposition exposure period and no parasitism was observed at this temperature. Like its host, *B. argentifolii*, the parasitoid survives the mild winters of coastal South Carolina. Populations of both increase with the warmer temperatures of the spring and summer. These data indicate that high temperatures of the summer are particularly conducive to parasitism by this parasitoid.

Investigator's Name(s): Steven E. Naranjo.

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Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control.

Dates Covered by the Report: January 1999 - December 1999

Intraguild Predation on Whitefly Parasitoids

Studies were continued to quantify comparative predation by generalist predators on parasitized and unparasitized whitefly (*Bemisia tabaci*) hosts in cotton. Adult females of *Geocoris punctipes*, *Orius insidiosus* and *Hippodamia convergens* were provided equal numbers of parasitized (*Eretmocerus emiratus*) and unparasitized early 4th instar whiteflies in petri dish arenas and allowed to forage for 24 h. Studies were conducted with early instar parasitoids (displacement of host mycetomes) and with pupal-stage parasitoids. All three predator species displayed a significant preference for parasitized hosts. Preference was consistently strongest for pupal-stage parasitoids in all three predators. Comparing predators, *H. convergens* exhibited the strongest bias for parasitized hosts; responses by *G. punctipes* and *O. insidiosus* were similar to one another. Early 4th instar whitefly are very flat and almost translucent on the leaf surface. In contrast, once the immature parasitoid is large enough to displace the host's mycetomes the host begins to swell and become opaque. Thus, parasitized hosts may be more apparent to predators foraging on the leaf surface. This hypothesis was tested by presenting parasitized host along with late-stage 4th instar whitefly (this stage also swells and is opaque). Both *G. punctipes* and *O. insidiosus* showed no significant preference in these arenas supporting the hypothesis that preference for parasitoids may be based on visual cues. In contrast, *H. convergens* still showed a significant (albeit lesser) preference for parasitized hosts suggesting that other factors are involved in prey choice by this beetle. These data will aid ongoing efforts to model biological control of *B. tabaci* in cotton, and help to more accurately estimate marginal mortality rates due to parasitism in ongoing life table analyses.

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Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control.

Dates Covered by the Report: January 1998 - December 1999

Conservation of Whitefly Natural Enemies in Conventional and IGR-based Management Systems

Studies were continued in 1998 to examine the comparative effect of two new insect growth regulators (IGR) and conventional insecticides on the abundance and activity of native natural enemies of *Bemisia tabaci*. Overall results were very similar to those observed in 1997. Mean rates of parasitism by *Eretmocerus eremicus* and *Encarsia meritoria* rarely exceeded 50 % in any treatment plot on any sample date and differences among treated and untreated control plots were generally insignificant. Parasitism was consistently higher in plots that received no insecticides for control of *Lygus hesperus* (split-plot treatment) compared with plots that were treated. Results for predators were more definitive. Population densities of most predators examined were significantly lower in plots treated with conventional insecticides compared with the untreated control. The IGRs caused reductions in several predator species compared with untreated controls. Based on seasonal means, densities of *Orius tristicolor* were depressed about 29% in pyriproxyfen-treated plots and densities of *Drapetis* spp.(a predatory fly) were depressed about 46-54% in buprofezin and pyriproxyfen plots (compare to 62% reduction in conventional plots). Neither IGR significantly depressed populations of any other predator species. Insecticide applications for *Lygus* bugs consistently depressed populations of all predator species. Combined results from 2 years of studies suggest that use of IGR conserve populations of important natural enemies that help regulate *B. tabaci* and other key cotton pests. These studies were conducted for a 3rd year in 1999 and results are pending.

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Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control.

Dates Covered by the Report: June 1998 - December 1999

Biology and Bionomics of *Encarsia Transvena* (Timberlake) on *Bemisia Tabaci* Genn. in Cassava

Encarsia transvena is a predomiant aphelinid parasitoid on *Bemisia tabaci* in cassava ecosystem. Investigations carried for the last one year are embodied in this paper. Host searching behaviour and biology of the parasitoid were studied in detail. Behavioural pathway involves searching, grooming, host encounter, tapping on the host by antenna and arriving over the host, to find suitable site for its oviposition. Time taken from encounter to oviposition was 46 sec.; from insertion to withdrawal 239.2 sec. and feeding time was 216 sec. Studies on *E. transvena* revealed that females laid fertilized eggs in whitefly nymphs preferably 3rd and 4th instars giving rise to females. Developmental duration of female parasitoid on four instars of *B. tabaci* were recorded. Female parasitoid passed through three larva instars. The development from egg to adult took 12-15 days. Adult female laid eggs shortly after its emergence. Biometrics of different stages of the parasitoid were also presented. Field observation revealed presence of *E. transvena* throughout the year. Field parasitisation ranged from 0.73-19.71% and in the net house condition it ranged from 33.3 to 69.1%.

Investigator's Name(s): C. H. Pickett, G. S. Simmons[1], E. Lozano[1], & J. A. Goolsby[2].

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Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control.

Dates Covered by the Report: February 1998 - May 1999

Augmentative Biological Control Using Transplants

We report on a novel approach to enhancing early season field populations of *Eretmocerus* sp. using cantaloupe transplants. Cantaloupe seedlings prior to placement in fields were inoculated with a highly specific whitefly parasite, an *Eretmocerus* population recently imported from the United Arab Emirates. We want to determine whether control of whiteflies in fields receiving transplants inoculated with parasites, or "banker plants," is more effective than in fields receiving conventional hand releases. We also want to show that transplants with parasites can be integrated into imidacloprid treated fields at very little additional cost, or at least equal to conventional insecticide costs.

We completed our second field season spring 1999. Parasites were released into commercial farms of cantaloupe in the Imperial Valley. In 1998 and 1999 we conducted a replicated study at an organic grower, where we compared the effect of banker plants (transplants with parasites) against plots receiving hand-releases of parasites, and a no-release control. Treatments were assigned to 1/3 ac (1998) and ½ ac (1999) plots using a randomized complete block design with 4 replicates. The other growers used the conventional product imidacloprid (Admire®) for silverleaf whitefly control, where we compared whitefly plant densities in paired 1 acre plots, with and without the addition of banker plants, respectively. We randomly selected 40 leaves bearing early to late instar nymphs, from each treatment plot.

In 1998 and 1999 we measured significant differences in whitefly nymphal populations between the different treatment plots at the organic site. Both years, the whitefly numbers were lowest in the plots receiving parasites. However, no consistent, significant differences were detected when comparing population means between hand-released parasites and those entering fields on transplants. Parasitism means were generally higher in the transplant plots in 1998, but a little lower than those in the hand release plot in 1999; whitefly numbers were generally lowest in the transplant plots in 1998, but mixed in 1999. Whitefly numbers in transplant plots were significantly lower than both the control and hand release plots on the last sample date in 1998.

We were successful in augmenting the parasite population in one conventional field in 1999; the conventional field in 1998 never developed a whitefly population, and we were too late in getting our plants into the other 2 conventional fields in 1999; many of the transplants died in their transfer. Parasitism levels in the 1999 conventional field were several fold greater than in the control; maximums were 16% versus less than 1%. Outside of our plot, the conventional field essentially lacked parasitism. This difference was reflected in the silverleaf whitefly population: a maximum of 4 whiteflies per cm^2 in the control plot and 1.2 in the treated plots. Furthermore, these results show that the parasites on the transplants not only survived through the imidacloprid treatment but reproduced a new generation. This finding is supported by data from the other two conventional fields treated with imidacloprid. The number of parasitized whitefly on transplants five weeks after placement in these fields was approximately the same as on plants used in the transplanting, but held back and grown under controlled conditions at the USDA field station.

Investigator's Name(s): C. H. Pickett, E. Lozano[1], & D. Overholt[2].

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Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control.

Dates Covered by the Report: August 1997 - November 1999

Fall Releases of Parasites into Citrus

The silverleaf whitefly (*Bemisia argentifolii*) was an increasingly important pest of cotton in the San Joaquin Valley from 1994 through 1997 when this project was initiated. Field studies suggested that citrus had become an important overwintering site for this whitefly. Cotton has the highest incidence of whitefly infestations in areas of the Valley with a matrix of both citrus and cotton. We report on large scale releases of *Eretmocerus emiratus* (M95104), *Eretmocerus* nr. *emiratus* (M96076, Ethiopia), *E. mundus* (M92014), and secondarily *E. hayati*, and trace numbers of *Encarsia transvena* (M95107) (a possible contaminant) into four citrus groves. The study has two goals: (1) to determine if exotic parasites released into citrus during the fall will overwinter in this habitat and move into cotton the following spring; and (2) to permanently establish new populations of exotic parasites specific for the silverleaf whitefly.

Three study sites were identified initially, one each in Fresno, Tulare, and Kern Counties. A fourth was added because one of the original growers stopped farming cotton (Kern Co.). Sites consisted of citrus and cotton acreage managed by the same owner. Cotton is grown directly adjacent to the citrus, and growers have had a history of silverleaf whitefly problems. We began releasing parasites in early August or September 1997, 1998, and 1999 when migrating whitefly nymphs were first recorded from citrus leaves. Over 100,000 parasites were released weekly at each location and a total of 4.05 million were released in 1997, over 10 million in fall 1998, and 3.1 in 1999. The dispersal of the released parasites was recorded using sticky cards with identification based on the adult males since they could be readily distinguished from native *Eretmocerus* while on the sticky cards.

Whitefly migration into orchards was ongoing when we began sampling in August 1997, but didn't commence until late September in 1998 and 1999. The delay in cotton maturity, as a result of a the cool spring, undoubtedly played a role in forestalling the emigration of whiteflies from this preferred host plant. Parasitism of silverleaf whitefly on citrus was always quite low, even in the second year of releases, rarely exceeding 10%, despite the massive releases of parasites into these trees (see Pickett & Overholt, this volume).

Our weed survey data shows that the released parasites are capable of surviving during winter months on a number of weedy plants common to citrus orchards. We also found parasitized whiteflies on weeds in spring and summer when few if any whiteflies were recorded from citrus. Their abundance appears to be associated with the abundance of weeds in and around the citrus orchard from where we were sampling. The grower in Tulare County had the cleanest orchard and host weeds were extremely difficult, if not impossible on some occasions, to find. He had the lowest presence of overwintering parasites on weeds.

Exotic parasites have been recorded from three of four cotton fields adjacent to orchards, one year after releases. The one exception to date has been the most recently added release site, Cappello's in the southern end of Kern Co. No whiteflies were recorded from cotton this last summer, thus no whitefly hosts were available for parasitism. Parasitism levels shown at the Tulare and Fresno county farms reflect mixed populations of native and exotics. All recovered and identified parasites at the original Kern County site have been exotic; therefore the parasitism levels resulted entirely from our releases. Parasitism was recorded early in the season at all sites showing that these parasites can rapidly find and attack silverleaf whitefly present at very low numbers. All samples were taken within 100 yards of the orchard.

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Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control.

Dates Covered by the Report: August 1997 to November 1999.

Tracking the Impact of Released Parasites using Sentinel Plants

The establishment and impact of silverleaf whitefly (*Bemisia argentifolii*) has been difficult to track. The whiteflies attack a broad range of annual and perennial plants in a wide range of habitats that include both urban settings and agricultural. Sentinel plants have been used to monitor parasitism of other pests when they were difficult to locate in the environment (Marston, N. 1980. Sampling parasitoids of soybean insect pests, *In* Kogan & Herzog (Eds.), Sampling Methods in Soybean Entomology). Sentinel plants allow for sampling in a variety of habitats, independent of host plant type, without concern for impacts from insecticides, and independent of the host plant density. We developed a sentinel plant sampling system to measure the change in parasite species composition and the change in magnitude of parasite oviposition by introduced exotics, over and above that attributable by natives.

We started using hibiscus cuttings as sentinel plants in 1998 but switched to cotton plants in 1999 due to contamination problems. Plants were grown from potted seed, isolated in individual cages. After two weeks of exposure to adult whiteflies, one foot tall plants were placed outdoors at 30 protected sites in the southern San Joaquin Valley, two plants per site. After one week of exposure to extant parasites, plants were placed back into individual cages, allowing approximately 2 weeks for additional incubation of insects. Leaves were then stripped from plants allowing for adult whitefly and parasite emergence under controlled conditions. These individuals were counted and recorded for each of four monthly sampling events during the latter part of 1998 and 1999.

Most of the problems encountered during our first two years using sentinel plants were overcome. We eliminated contamination of sentinel plants and were able to produce a cotton sentinel plant that could withstand field conditions. This method is apparently sensitive to low populations of parasites. We picked up native parasites during the first run in May 1998 at 6 of 26 sites. The regional whitefly population in the San Joaquin Valley was exceptionally low in 1999. Parasites weren't picked up until September when sentinel plants from 10 of 29 sites captured parasites; 4 of these captured exotic *Eretmocerus*. Exotic *Eretmocerus* made up 11% of all captured species when including *Encarsia* spp, and 80% when excluding them. One third of the *Encarsia* were *Enc. inaron*, introduced for control of the ash whitefly, *Siphoninus phillyreae* (Haliday). All of the remaining were *En. pergandiella*, except for one *En. meritoria*. Exotic *Eretmocerus* made up 0.16% of emerged adult insects (parasites + silverleaf whitefly) and natives made up 0.04%.

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Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control.

Dates covered by the report: 1995 to 1999

Establishment of Introduced Parasitoids of the Silverleaf Whitefly in Imperial Valley, CA

Since 1994, a number of exotic *Eretmocerus* and *Encarsia* species/strains have been evaluated in field cages, and released in large numbers in commercial fields, refuge nursery plots and urban yards. The most promising *Eretmocerus* for this desert region include *E. emiratus* Zolnerowich & Rose, *E.* nr. *emiratus* from Ethiopia and *E. mundus* Mercet. *Encarsia sophia* (=*Encarsia transvena*) from Maltan, Pakistan appears promising as well. Identification to species was accomplished using recently published keys and by DNA analysis (RAPD-PCR) by the USDA-APHIS, Mission Biological Control Center, Mission, TX.

Parasitoid population development in long-term refuge nursery plots from 1994-1999: From 1994 through 1997, species of exotic parasitoids were released into long-term refuge field plots on multiple occasions each year. Plots (1/2 to 1 acre) were located at the Imperial Valley Research Center near Brawley, CA, and at an organic farm at the south end of the county. During the warm season, the plots consisted of okra and basil. During the cool season, cole crops (esp. collard) and sunflower were present. Kenaf, roselle and eggplant were also periodically present (1994-1996) along with adjacent plantings of cotton and spring cantaloupe. Leaf samples were taken approximately 6 times during each year to determine the status of parasitoid population increase and persistence. Nether *E. tejanus* nor *E. stauferi* (i.e., *Eretmocerus* spp. from Texas) have been recovered following their release. During 1995, *E. melanoscutus* was released in large numbers beginning in early August. Recoveries of this parasitoid were rare. Releases of *E. mundus, E. hayati* and *E. emiratus* began in April of 1996. Numbers of exotic parasitoids compared to natives were high during early summer, however, the proportion of the sample consisting of exotic species dropped markedly by late July, indicating poor performance (population increase and persistence) during this very warm summer period. During 1997, *E. emiratus* and *E.* nr. *emiratus* were released. The relative performance of exotics was considerably better than in 1996. The proportion of exotic *Eretmocerus* relative to native *Eretmocerus eremicus* declined once again during late summer, however, not to the same extent. During 1998, **none of the long-term refuge plots were inoculated** with exotic whitefly parasitoids. This made possible the assessment of populations released in previous years at these sites, in terms of their ability to overwinter and compete with native species of silverleaf whitefly parasitoids. Overwintering on cole crops was confirmed albeit in low numbers. During the summer of 1998 and 1999, *Eretmocerus* densities soared on okra, basil and adjacent cotton. By late August there was a greater proportion of exotic *Eretmocerus* (upwards of 80% on okra and cotton) than native *Eretmocerus.* The order of dominance of exotic *Eretmocerus* species is *E.* nr. *emiratus, E. emiratus* and *E. mundus. Encarsia sophia* has reached high densities during the summer and fall of 1998 and 1999 in several of the refuge field plots as well.

Regional surveys: During late summer and fall of 1998, exotic *Eretmocerus* were collected from numerous ornamental plants in several communities in Imperial Valley. In addition, leaf samples were obtained from three edges of a number of conventionally managed cotton fields during September of 1998 and 1999. The fall samples of ornamental plants at 15 urban sample sites in three communities indicate that exotic *Eretmocerus* were present in 10 of 15 sites. On average, 25% of the *Eretmocerus* at the 10 locations was exotic. Among cotton fields, exotic *Eretmocerus* were detected in 9 of the 23 fields (i.e., 39%) sampled in the fall of 1998 and in 31 of 42 fields (i.e., 74%) sampled in the fall of 1999. In those fields where exotics were detected, 6% of the *Eretmocerus* were exotics in 1998 and 23% were exotic in 1999. Similarly, an increase in *Encarsia sophia* was noted as well from 1998 to 1999. *Encarsia sophia* was detected in only one of 23 cotton fields (i.e., 4%) in 1998 and in 27 of 42 cotton fields (64%) in 1999.

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Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control.

Dates Covered by the Report: 1997 to 1999

Encarsia sophia Reproduction Patterns

Encarsia species have been utilized effectively in numerous biological control projects and have commonly been identified as the primary agent responsible for control. This genus of Aphelinids is well known for its varied and ostensibly unusual reproductive biology. Some species are only known to be uniparental primary parasitoids, whereby males are absent or very rare. Comparatively few known arrenotokous species of *Encarsia* are characterized by diploid females and haploid males that are both primary parasitoids [e.g., *E. inaron*/ ash whitefly host]. Many have a heteronomous hyperparasitic mode of reproduction characterized by females that are primary parasitoids of whiteflies, whereas males develop on conspecific female parasitoid pupae or pupae of other species. Representative species such as *E. opulenta* and *E. lahorensis* have been instrumental in achieving biological control of the citrus blackfly and citrus whitefly respectively. Theoretically based questions have been raised relative to the potential of heteronomous hyperparasitic species interfering with biological control activities of other parasitoid species targeted for use in biological control programs. The ability to exploit females of another parasitoid species for male production represents an additional means by which a heteronomous hyperparasitoid may compete with other species. This is in addition to such common practices by numerous parasitoid taxa of host feeding, superparasitism, and multiple parasitism; traits that also may play important roles in interspecies interactions.

Four populations of *Encarsia sophia* (=*E. transvena*) as well as two other species of heteronomous hyperparasites have been evaluated in field cages in Imperial Valley, Ca for their potential to control *Bemisia argentifolii* (SLW). *Encarsia sophia* from Multan, Pakistan demonstrated a distinct ability to rapidly increase its densities during the hottest time of the year, whereas all other populations and species performed poorly during this time. This population of *Encarsia sophia* has become established and has increased in abundance since 1997. The objectives of this study are to: 1) Determine the generalized temporal patterns of *Encarsia sophia* sex ratio; 2) Identify *E. sophia* sex ratio fluctuations relative to whitefly population fluctuations; and 3) Identify uniformity of sex ratios relative to species of whitefly hostplants.

METHODS: Within a home yard in Brawley, CA represented by 19 silverleaf whitefly host plant species (plus multiple varieties), whitefly and parasitoid densities are monitored. *Encarsia sophia* and *Eretmocerus* spp. pupae are isolated in individual cells within plastic trays and allowed to emerge to determine the sex ratio. This is primarily done for broccoli, collard and ornamental hibiscus, the most commonly attacked plants on site. Similar methods are employed for monitoring whitefly host plants grown together as strips within ½ to 1-acre field plots. Plant species include okra, basil, collard, sunflower, and cotton.

RESULTS: In 15 of 16 samples obtained from broccoli and collard in 1998 & 1999, the *E. sophia* population consisted of over 50% females, and commonly exceeded 90% females. Similar results were obtained from field plot samples. Reductions in % females (i.e., extensive male production) were associated with a precipitous decline of whitefly density following peak seasonal whitefly density cycles. These peak activity periods were at times initiated by large influxes of whitefly from remote "outside sources" during late summer. This was observed in both home yard and field plots sites. Sex ratios were usually homogeneous across plant species environments (i.e., basil, hibiscus, collard and broccoli).

DISCUSSION: *Encarsia sophia* appears to be typified by high rates of female progeny production. Data suggest that widely fluctuating whitefly densities precipitate wide fluctuations in sex ratios. It is further suggested that female offspring production predominate during the initial phases of whitefly increase and during times of low whitefly fluctuations. As suggested by data collected to date regarding the homogeneity of sex ratios across plant types, the production of female offspring typically predominates throughout a vegetationally diverse environment. *Encarsia sophia* is known to exploit other species including *Eretmocerus* to produce males of its own species. Based on field cage studies and field releases, the Multan strain of *E. sophia* has a remarkable capacity for inflicting high levels of parasitism on whitefly populations on certain host plants during the hottest period of the year in Imperial Valley. The tradeoff between its ability to directly impact whitefly populations and its negative impact on other parasitoid species has yet to be fully determined. However, its propensity toward female offspring production and high levels of parasitization suggests that it is a potentially valuable natural enemy.

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Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control.

Dates Covered by the Report: Field Season: July - December 1998

Dispersal of *Serangium parcesetosum* (Coccinellidae) on Poinsettias Infested with *Bemisia argentifolii* (Aleyrodidae) in Greenhouse Trials

Releases of *Serangium parcesetosum* were evaluated for their ability to disperse throughout a greenhouse crop of poinsettias infested with *Bemisia argentifolii*. Whiteflies were introduced at a rate of 1.25 adult/plant in week 0 (Sep 8) into two separate greenhouses. Plants in each greenhouse were grouped into three quadrats, with 48 plants per quadrat, arranged 4 rows by 12 columns of plants. Single plants were potted in 15 cm pots, spaced 15 cm apart. Leaf samples were collected on a weekly basis and examined with a dissecting microscope. The number of live immature whiteflies were recorded, grouped into three growth stages: egg, small nymphs (= instars1+2), large nymph (= instars 3+4). Whitefly densities are expressed herein as the mean number of individuals per 25 sq cm. Releases of *S. parcesetosum* were made on weeks 5, 7, and 9. Beetles were tagged with three different fluorescent colored powders, and similarly tagged beetles were released on a central plant in each quadrat. The relative dispersal of *S. parcesetosum* was observed following releases in the greenhouse areas, and was assessed based on the location of recoveries after 48 hours. Beetle dispersal was grouped into three categories: 1) low, recovered within 0-2 plants from release point, 2) moderate, recovered within 3-5 plants, 3) high, recovered in a different quadrate. Three mark-recapture trials were preformed.

In the first mark-release trail (Oct 19) 270 beetles were released, 9.6% recovered, and the relative dispersal among the recoveries was 64% low, 18% moderate, and 18% high. Mean whitefly densities during this release were 4.21 eggs, 1.00 small nymphs 1+2, 0.70 large nymphs. (Visual observations of beetles during the first trial suggested too much powder was used which interfered with their mobility.) Tagging methods were modified in the following trials, tagging adult beetles with a small quantity of colored powder. In the second trial (Nov 1), 300 beetles were released, 25% recovered, and the relative dispersal among the recoveries was 47% low, 29% moderate, and 37% high. Mean whitefly densities during this trial were 4.68 eggs, 7.38 small nymphs, 0.48 large nymphs. In the third trail (Nov 17), 300 beetles were released, 37% recovered, and the relative dispersal among the recoveries was 65% low, 22% moderate, and 13% high. Mean whitefly densities in the third trial were 12.28 eggs, 13.78 small nymphs, 4.88 large nymphs. Results of the mark-recapture investigation suggest that releases of *S. parcesetosum* will disperse successfully throughout a greenhouse crop of poinsettias. However, the data indicates that if host densities are high, the beetles may not disperse as readily as when whitefly densities are low. Visual observations indicated that beetles spent the majority of their time host-searching.

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Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control.

Dates Covered by the Report: Field Season: July - December 1998

Biological Control of *Bemisia argentifolii* (Aleyrodidae) Infesting Poinsettias: Evaluation of *Encarsia formosa*, Nile Delta Strain, (Aphelinidae) and *Serangium parcesetosum* (Coccinellidae)

Releases of *Encarsia formosa*, Nile delta strain, and *Serangium parcesetosum* were evaluated for their ability to control *Bemisia argentifolii* infecting a greenhouse crop of poinsettias. Three treatments were used to assess the impact of natural enemies released on *B. argentifolii*: 1) releases of *E. formosa* and *S. parcesetosum*, 2) releases of *S. parcesetosum* only, and 3) each greenhouse area with 12 plants caged to exclude natural enemies. Whiteflies were introduced at a rate of 1.25 adult/plant in week 0 (Sep 8) into two separate greenhouses, each containing 144 potted poinsettia plants. Weekly releases of *E. formosa* began on week 4 and continued up to week 11, and releases of *S. parcesetosum* were made on weeks 5, 7, 9. Both of the natural enemies, *E. formosa* and *S. parcesetosum*, were released at a rate of ~1 adult/plant. Leaf samples were collected on a weekly basis and examined with a dissecting microscope. The number of live immature whiteflies were recorded, grouped into three growth stages (egg, instars 1+2, instars 3+4). The number of dead whiteflies was also recorded, distinguishing the cause of death as being either by predation or parasitism.

Whitefly densities within the exclusion cages were considerably greater than those of each of the two natural enemy treatments. In areas receiving natural enemies, whitefly densities increased, reaching maximum densities in week 10, and decreased over the following 3 weeks. At the end of the study (week 13: December 8), in the greenhouse area receiving both natural enemies, the whitefly population was less than 1/100 the size of the population in the corresponding exclusion cage; in the area receiving *S. parcesetosum* only, the whitefly population was ~1/50 the number in its respective exclusion cage. However, whitefly numbers on poinsettia plants were above acceptable market standards in both areas. Earlier releases of natural enemies may have produced a more acceptable crop. In the area receiving both natural enemies, *E. formosa* did not become well established (probably due to a high level of predation by *S. parcesetosum*) and very little parasitism of whiteflies was observed.

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Research & Implementation Area: Section D: Natural Enemy Ecology and Biological Control.

Dates Covered by the Report: January 1-November 30, 1999

Whitefly Biocontrol Agents: Differentiation of Parasitoid Wasps by Satellite DNA-targeted Hybridization

The whitefly *Bemisia argentifolii* (Silverleaf whitefly) is among the most serious pests of cotton and horticultural crops around the world. With the increasing resistance of whitefly populations to insecticides and the emphasis on reduced usage of noxious chemicals, biological control of whiteflies in field environments has become a major interest. A longstanding approach to control of whitefly populations in greenhouses employs *Encarsia formosa*, a natural enemy of the whitefly. Studies have been initiated by USDA--APHIS, on the release of exotic species of another microhymenopteran genus, *Eretmocerus*. These insects, originating from Pakistan, Spain, United Arab Emirates, and Ethiopia, augment the limited parasitism of native U.S. *Eretmocerus* species on whiteflies in the field. Effective assessment of these ongoing studies requires that the parasitizing hymenopteran be identified. The small size and similar physiological and anatomical characteristics of the various *Eretmocerus* species makes morphological identification of the adult insects difficult, and early-stage larvae within the whitefly are nearly impossible to detect and distinguish.

Species-specific DNA probes have been used for the detection of other insects. In this communication, we report progress on the development of specific DNA probes for several species of *Eretmocerus*. Our approach targets species-specific components of the satellite DNA present in these organisms. Satellite DNA is comprised of a number of different high-copy-number repeated sequences localized in telomeric, centromeric, and intergenic regions of chromosomes; these sequences are widely divergent in eukaryotic organisms. We have cloned and characterized satellite sequences from two foreign species, *E. mundus* (Spain) and *E. hyati* (Pakistan), and from one native U.S. species, *E. eremicus*. We have also developed a probe for the greenhouse biocontrol agent, *Encarsia formosa*. Typically, each of the characterized sequences comprises 1-3% of the genome. The lengths of the repeat units in the characterized clones are: *E. mundus* (sequence-3), 172 bp; *E. mundus* (sequence-7), 348 bp; *E. hyati*, 251 bp; *E. eremicus*, 144 bp; and *E. formosa*, 33 bp. Specificity studies performed with insect squash blots indicate that the DNA probes from *E. eremicus* and *E. formosa* are completely specific and the probe from *E. hyati* is nearly species-specific (3% cross reaction only with *E. emiratus*). The probe from *E. mundus* hybridizes with the genome of all foreign species tested, but not with *E. eremicus* or *E. tejanus*; thus, it is useful for differentiating between foreign and native U.S. species of the parasitoid. Genomic libraries also have been prepared from the DNA of two foreign wasps (*Eretmocerus* sp. (Ethiopia) and *E. emiratus* (United Arab Emirates)), and screening and characterization of the clones is in progress.

We have also evaluated the utility of a DNA probe for detection of parasitism in whitefly nymphs collected from cotton fields where selected numbers of *Eretmocerus* sp. (Ethiopia) had been released. Whitefly nymphs with no obvious signs of parasitism (*i.e.*, eggs, egg rings, or displaced mycetomes) were squashed on membranes and hybridized with radiolabeled *E. mundus* DNA probe; other nymphs were examined by standard non-molecular methods used in this laboratory. Both approaches showed similar, low levels of parasitism in the whitefly population.

Future efforts will include the selection of DNA probes from additional U.S. species, *E. tejanus* and *E. transvena*, the use of the array of cloned sequences in the development of nonradioactive detection systems for the various parasitoids, and additional validation of the detection methods with field-collected insects.

Research Summary

Section D: Natural Enemy Ecology and Biological Control

Compiled by: James Hagler and Matt Ciomperlik

Biological control research continues to serve as a major focal point in the development and implementation of a management plan for silverleaf whitefly, *Bemisia argentifolii*. Significant progress is been made toward introducing, augmenting, and conserving whitefly natural enemies. Moreover, other research areas of the National Silverleaf Whitefly National Research, Action, and Technology Transfer Plan (i.e., ecology, chemical control, host-plant interactions) are giving full consideration to natural enemies in their research programs. Herein we summarize the research progress made during 1999. We divided this summary into four categories: foreign exploration (classical biological control), augmentation, conservation, and natural enemy biology.

Foreign Exploration (Classical Biological Control). The foreign exploration for natural enemies of *B. argentifolii* is largely completed. However, an evaluation of the spread and establishment of the exotic natural enemies released in the United States continues. Research from Texas, Arizona, and California shows that several exotic parasitoids have survived over the years and they are showing signs of establishment. In Texas, *Eretmocerus mundus* and *Er. hayati* comprise an increasing percentage of the parasitoids recaptured from spring crops. Exotic *Er. hyati*, originally collected from Pakistan appear to be widely distributed in the four counties that comprise the lower Rio Grande Valley of Texas (LRGV). Field samples from the LRGV show large numbers of *Er. mundus* recovered predominantly from cole crops, while *Er. hyati* has been recovered in large numbers from all crop types. In California and Arizona, a number of exotic *Eretmocerus* and *Encarsia* species/strains have been released in large numbers in commercial fields, refuge plots and urban areas. The most promising parasitoids for this desert region include *Eretmocerus emiratus* Zolnerowich & Rose, *Er.* nr. *emiratus* from Ethiopia, *Er. Mundus* Mercet, and perhaps, *Encarsia sophia* (= *En. transvena*) from Pakistan.

Natural enemy refuges have been grown over the past five years in Brawley, California. Each year the proportion of exotic parasitoids recaptured from the refuge areas increases (i.e., 80% recaptured in 1999 were exotic). Regional surveys in ornamental plants and in cotton fields near Brawley showed that exotic *Eretmocerus* were present in 67% and 74% of the fields sampled, respectively. These data suggest that the exotic parasitoids are beginning to spread and establish throughout the region.

Effective assessment of classical biological control requires that the exotic parasitoids be accurately identified. Parasitoid identification has become easier with recently published taxonomic keys; however, the identification of the various parasitoids is still tedious. The small size and similar physiological and anatomical characteristics of the various *Eretmocerus* species makes morphological identification of the adult insects difficult. Moreover, early-stage larvae within parasitized whiteflies are nearly impossible to detect and distinguish. Species-specific DNA probes have been developed for the detection of several species of *Eretmocerus*. DNA sequences have been characterized for two exotic species, *Er. mundus* (Spain) and *Er. hyati* (Pakistan), and for one native species, *Er. eremicus*. A probe has also been developed for the greenhouse biocontrol agent, *En. formosa*. Specificity studies performed with insect squash blots indicate that the DNA probes from *Er. eremicus* and *En. formosa* are completely specific and the probe from *Er. hyati* is nearly species-specific. The probe for *Er. mundus* hybridizes with the genome of all foreign species tested, but not with *Er. eremicus* or *Er. tejanus*; thus, it is useful for distinguishing between foreign and native parasitoids. Genomic libraries also have been prepared from the DNA of two foreign wasps (*Eretmocerus* sp. (Ethiopia) and *Er. emiratus* (United Arab Emirates), and screening and characterization of the clones is in progress. Future research will include selecting DNA probes from *Er. tejanus* and *En. transvena* using the array of cloned sequences in the development of nonradioactive detection systems for the various parasitoids, and validating the detection methods with field-collected insects.

Augmentation
Silverleaf whitefly is susceptible to fatal infection by *Beauveria bassiana* and *Paecilomyces fumosoroseus*. *B. bassiana* rarely occurs naturally in *Bemisia* populations, but it has been used successfully as a mycoinsecticide on other pests. Naturally occurring *P. fumosoroseus* has been seen to infect *Bemisia* populations. Although the general biology of these fungi is well studied, further studies are needed to improve their efficacy. Tests were conducted to determine if sugars that occur in association with *Bemisia* increase fungal spore germination. The addition of simple sugars (sucrose, melezitose, and trehalose) had little effect on germination. However, an exogenous source of protein (peptone or yeast extract) stimulated 95-100% germination for both fungi.

Further studies were conducted to see if sugars play a role in fungal growth and infectivity after the spores have germinated. When germinated spores were applied to 3rd instar whiteflies, the mortality was increased 245%. Moreover, at a concentration where fresh spores caused only 12% mortality, germinated spores caused 41%.

In another experiment, two different strains of *B. bassiana* (Mycotrol® and Naturalis-L®) were tested against *B.*

argentifolii in Arizona, California, Florida, and Texas on a wide variety of crops. Mycotrol® caused 76-94% mortality of *B. argentifolii* nymphs under humid conditions. Furthermore, Mycotrol® also provided good whitefly control on subsurface irrigated cantaloupe in Arizona, whereas Naturalis-L® did not. These studies showed that fungi could play a role in whitefly management, although their usefulness may be limited to extremely humid environments.

A key component to the successful use of parasitoids in an augmentative biological control program is having a reliable method to release the biological agents. A study was conducted that compared the efficacy of four parasitoid release protocols. The variables examined included parasitoid emergence, survival, dispersal and mating success. Additionally, the cost of each method was evaluated to determine the most economical method for releasing parasitoids. The efficacy of each method varied, but in general it was determined that a paper-cup method (i.e., known amounts of parasitized whitefly pupae were put in cups and placed in the field for emergence) was the most efficient and cost effective method tested.

Citrus orchards were determined to be an overwintering site for whiteflies in the San Joaquin Valley, CA. A total of 17 million *Er. emiratus*, *Er.* nr. *emiratus*, *E. mundus*, *Er. hayati*, and *En. transvena* were released into four citrus groves. Parasitism of silverleaf whitefly on citrus was always low, rarely exceeding 10%, despite the massive releases of parasitoids into the orchards. A survey of weeds commonly found in citrus orchards showed that the released parasitoids were capable of surviving during winter months. Parasitized whiteflies were found on weeds in spring and summer when few whiteflies were seen on citrus. Parasitoid abundance was positively correlated with the abundance of weeds in and around the citrus orchard from where the samples were taken. In conclusion, it appears that citrus is a poor host for silverleaf whitefly.

A novel method for augmenting whitefly parasitoid populations is being developed that uses cantaloupe transplants inoculated with high concentrations of *Er. emiratus* (banker plants). Results showed that fields receiving banker plants produced only slightly greater whitefly control than those fields where a conventional release protocol was used.

The predator *Serangium parcesetosum* is a potential augmentative biological control agent for *B. argentifolii* in greenhouses. A study was conducted on the population dynamics of *B. argentifolii* on caged poinsettias exposed to *S. paresetosum*. Whitefly mortality increased dramatically within two weeks after a single *Serangium* release, and whitefly densities remained constant at the time of predator introduction for the ensuing 10-week study period. It appears that whitefly control was primarily due to the prolonged survival and continuous feeding of the beetles. In conclusion, *Serangium* is a potential biological control candidate for whiteflies infesting greenhouse poinsettias.

The dispersal of *S. parcesetosum* was also evaluated in a greenhouse crop of poinsettias infested with silverleaf whitefly. Results suggest that *S. parcesetosum* will disperse successfully throughout a greenhouse crop of poinsettias. However, if host densities are high, the beetles may not disperse as readily as when whitefly densities are low. In another study, *En. Formosa* and *S. parcesetosum* were evaluated for their ability to control *B. argentifolii* infecting greenhouse poinsettias. Three release strategies were examined: 1) releases of *En. formosa* and *S. parcesetosum*, 2) releases of *S. parcesetosum* only, and 3) a no-release control. Data showed that whitefly densities were considerably greater in the natural enemy-free control cage than in each of the two natural enemy treatments. Additionally, the greenhouse area receiving both natural enemies had 50% fewer whiteflies than the area containing only *S. parcesetosum.* Unfortunately, whitefly numbers on poinsettia plants were above acceptable market standards in both natural enemy release areas.

The effects of temperature on insect life history was studied for two whitefly hosts, the silverleaf whitefly and the greenhouse whitefly, *Trialeurodes vaporariorum,* as well as the parasitoid, *Er. eremicus.* Development of *Er. eremicus* was faster when *B. argentifolii* was used as the host than *T. vaporariorum*. Additionally, mortality in *Er. eremicus* increased with temperature on *T. vaporariorum,* but decreased on *B. argentifolii.* In short, the life history of *Er. eremicus* was profoundly affected by its host.

Another series of experiments were conducted to determine the tritrophic interactions of silverleaf whitefly and greenhouse whitefly and two parasitoid species, *Er. eremicus* (a native species) and *Er. mundus* (an exotic species) on tomato. Natural mortality, developmental time, oviposition and progeny between the two whitefly species were not significantly different. However, the two species of *Eretmocerus* responded differently to the host whitefly species. *Er. mundus* developed faster, parasitized more nymphs, had more progeny, and had greater parasitism and emergence on *B. argentifolii* than on *T. vaporariorum.* These studies will be of value for developing rearing strategies for whitefly parasitoids.

Conservation

An enormous amount of progress is been made over the years toward conserving whitefly natural enemy populations. The introduction of biorational insecticides (e.g., whitefly growth regulators combined with BT cotton for controlling lepidopteran pests) has been a key component towards preserving whitefly predators and parasitoids.

Biorational fungi (*Beauveria bassiana* [Naturalis® and Mycotrol®] and *Paecilomyces fumosoroseus* [PFR-

97™]) and biorational whitefly growth regulators were examined for toxicity to predaceous natural enemies. Overall, there were only a few instances where these compounds did not reduce predator populations. Generally, these compounds resulted in a 17-35% reduction in predator populations when compared to no-treatment control plots. Virtually all of the compounds tested were highly toxic to *Hippodamia convergens* (80-100% reduction in population). In a separate experiment, the impact of whitefly growth regulators (buprofezin and pyriproxyfen) and conventional insecticides on the abundance and activity of native natural enemies was studied. Population densities of most predators examined were significantly lower in plots treated with conventional insecticides compared with the untreated control. The whitefly growth regulators caused reductions in several predator species compared with untreated controls. Based on seasonal means, densities of *Orius tristicolor* showed reductions of 29% in pyriproxyfen-treated plots and densities of *Drapetis* (a predatory fly) showed reductions of 46-54% in buprofezin and pyriproxyfen plots, as compared to 62% reduction in conventional plots. Neither whitefly growth regulator significantly reduced populations of any other predator species. Insecticide applications for *Lygus* bugs consistently reduced populations of all predator species. Combined results from two years of studies suggest that use of whitefly growth regulators conserve populations of important natural enemies, as compared to conventional insecticides.

Laboratory experiments were conducted to evaluate the direct effects of two whitefly growth regulators, buprofezin and pyriproxyfen, on survival and reproduction of *Geocoris punctipes*. Topical and contact assays revealed that buprofezin had no effect on survival or reproduction of 5th instar nymphs or adults. However, at high doses of buprofezin many nymphs molting to the adult stage had visible wing deformities that prevented successful mating and reproduction. Pyriproxyfen did not affect adult survival in either topical or contact residue assays over a wide range of doses. Reproduction also was unaffected at pyriproxyfen doses up to field application rates.

The lethal and sublethal effects of two commonly used defoliants, Def and Dropp, on the whitefly parasitoids, *Er. eremicus* and *Er. hyati*, were evaluated. It was found that the timing of application of the defoliants significantly affected parasitoid survival. Defoliant treatments applied to whitefly nymphs parasitized with early instar *Er. eremicus* larvae reduced the number of parasitoids produced.

Natural Enemy Biology
A series of studies were conducted to determine the effect of host age (at the time of parasitization) on the growth and development of *En. formosa*. This parasitoid was able to parasitize and complete its life cycle in all four whitefly instars. Parasitoid development was slower when 1st instar hosts were parasitized than when 2nd, 3rd or 4th instars were parasitized. The whitefly instar parasitized had no significant effect on the day in which *En. formosa* larval hatch was first observed. Interestingly, no matter which instar was parasitized, the parasitoid did not molt to the 3rd instar until the host had reached stage 4-5 of its last instar. It appears that the parasitoid's molt to its last instar depends upon some aspect of whitefly physiology. Although host instar parasitized had a effect on various aspects of parasitoid development, it did not influence the mean size of the parasitoid larva, pupa, or adult, nor did it affect percent emergence rate or adult longevity.

Studies were conduced to quantify predation by generalist predators on parasitized versus unparasitized whitefly. Adult females of *Geocoris punctipes*, *Orius insidiosus* and *Hippodamia convergens* were provided equal numbers of parasitized (*Er. emiratus*) and unparasitized early 4th instar whiteflies in petri dishes and allowed to forage for 24 h. Studies were conducted with early instar parasitoids and with pupal-stage parasitoids. All three predator species showed a preference for parasitized hosts. Of the predators tested, *H. convergens* exhibited the strongest bias for parasitized hosts.

The functional responses and interference of an indigenous parasitoid, *En. pergandiella* was compared with an exotic parasitoid, *Er. mundus*. Over the experimental host densities tested, the attack rates between *En. pergandiella* and *Er. mundus* were not significantly different. However, the handling time of *En. pergandiella* was higher than that of *Er. mundus*.

The influence of temperature on parasitism rates by the indigenous whitefly parasitoid, *Eretmocerus* sp. was examined. There was an increased rate of parasitism by *Eretmocerus* at temperatures above 20° and below 40°C. The rate of parasitism was highest between 25 and 35°C. At 45°C, the adult parasitoids did not survive.

Table D. Natural Enemy Ecology and Biocontrol.

Research Approaches[a]	Year 1 Goals Statement	Progress Achieved Yes	No	Significance
Natural control and conservation:				
Develop natural enemy conservation practices to reduce mortality to indigenous and introduced natural enemies.	Conduct life table analyses of indigenous and introduced natural enemies to identify key mortality factors of natural enemy populations.	X		New insect growth regulators tested well under field conditions, and reduced loss of natural enemies. A Life Table analysis was conducted on natural enemies in cotton.
Evaluate potential of alternate plants to act as in-field refuges or insectaries for natural enemies.	Identify potential plants for natural enemy population development and assess risks of these plants to foster additional pest problems.	X		Combinations of annuals and some perennials show promise as within field natural enemy refugia. They are attractive to parasites but support low numbers of whiteflies. Annuals served as outdoor insectaries when releasing exotic parasitoids.
Assess cues used by natural enemies to locate whitefly and to identify potential methods for enhancing natural enemy activity.	Conduct laboratory tests to identify cues used by natural enemies to locate and attack whitefly.		X	Some research has been initiated but was not reported at this meeting.
Augmentation of natural enemies:				
Develop natural enemy mass-rearing systems.	Identify natural enemies with the highest potential for controlling whitefly in key cropping systems.	X		Diets are being developed for generalist predators. Improvements have been made in rearing parasitoids, increasing rearing efficiency. Field studies have identified promising candidates for augmentative releases
Develop release technologies to maximize the effectiveness of mass-reared natural enemies in the field.	Identify natural enemies with the highest potential for controlling whitefly in key cropping systems and that may be economically mass produced.	X		A novel "Banker Plant" field release strategy shows promise for increasing efficacy of releases. Releases of *Eretmocerus* into greenhouses controlled *Bemisia* attacking poinsettias when done at low pest densites.

Table D. Natural Enemy Ecology and Biocontrol. (continued)

Research Approaches[a]	Year 1 Goals Statement	Progress Achieved Yes	No	Significance
Evaluate augmentative parasitoid, predator, or pathogen releases.	Initiate studies on natural enemy augmentation with identified high potential natural enemies.	X		Augmentative releases of parasitoids controlled *Bemisia* in large demonstration fields. These releases can be integrated with conventional pest management practices
Importation biological control:				
Evaluate the ability of exotic natural enemies to suppress whitefly populations under field conditions.	Identify sites suitable for the release and subsequent evaluation of each candidate natural enemy. Conduct inoculative releases of natural enemies.	X		Combinations of annual plants that make excellent insectaries and can be farmed under local climatic conditions have been identified. Homeowners are being recruited to care for plants used for making releases
Systematics, ecology, and population dynamics of natural enemies:[b]				
Clarify sytematics of predators, parasitoids and pathogens.	Conduct taxonomic studies of species within targeted releases sites. Verify taxonomic purity of mass-reared natural enemies. Complete taxonomic work on poorly characterized but important groups. Assist in determining most suitable natural enemies for release through biogeographical analysis.	X		Taxonomic studies have been completed on the exotic *Eretmocerus* and a key to their identification is in press. PCR techniques have been developed to identify the purity of cultures and aid in identification of recovered parasites.
Determine *Bemisia*- natural enemy-host plant (Tritrophic) interactions.	Initiate studies to identify mechanisms involved in *Bemisia*- and natural enemy plant attraction.	X		Controlled laboratory studies showed that *Bemisia* and aphelind oviposition rates varied depending on host plant.
Identify the attributes of natural enemy biology and population level interactions to explain biological control successes and failures.	Assess the value of the *Bemisia* biological control research to evaluate key issues to the science of biological control.	X		The role of autoparasitism in native populations of *Encarsia* and its impact on native *Eretmocerus* has been evaluated. Results from one study show no adverse affect of *Encarsia* on overall parasitism of SLWF

[a] See Table C for complementary research.
[b] See Table A for complementary research.

Table D. Natural Enemy Ecology and Biological control.

Research Approaches[a]	Year 2 Goals Statement	Progress Achieved Yes	No	Significance
Natural control and conservation:				
Develop natural enemy conservation practices to reduce mortality to indigenous and introduced natural enemies.	Evaluate predator gut contents. Conduct life table analysis.	X		Role of predators in cotton identified; importance of narrow spectrum insecticides highlighted.
Evaluate potential of alternate plants to act as in-field refuges or insectaries for natural enemies.	Determine refugia plant phenology in relation to cultivated crop phenology.	X		Perennial plants capable of growing in Imperial Valley identified, selected for a pilot project at a commercial organic farm.
Assess cues used by natural enemies to locate whitefly and to identify potential methods for enhancing natural enemy activity.	Determine potential methods for manipulating cues as part of a whitefly management program.		X	No work reported.
Augmentation of natural enemies:				
Develop natural enemy mass-rearing systems.	Determine nutritional, physiological, and ecological requirements for mass-rearing.	X		Whitefly, parasitized by *Encarsia*, were grown on an artificial diet long enough for parasitoids to emerge as adults. First such report. Potential for research and commercial rearing.
Develop release technologies to maximize the effectiveness of mass-reared natural enemies in the field.	Evaluate the fate of natural enemy life stages under field conditions to identify the appropriate developmental stage to be released.	X		First year results show banker plants may prove more efficacious than releases of parasitoids by hand. Two species of coccinellids evaluated, compared for greenhouse use.
Evaluate augmentative parasitoid, predator, or pathogen releases.	Conduct releases on selected crop systems at various rates of release.	X		Impact of *Beauveria bassiana* on generalist predators determined. Parasitoid dispersal was determined using new protein marking technique

Table D. Natural Enemy Ecology and Biological Control. (continued)

Research Approaches[a]	Year 2 Goals Statement	Progress Achieved Yes	No	Significance
Importation biological control:				
Evaluate the ability of exotic natural enemies to suppress whitefly populations under field conditions.	Evaluate establishment of exotic natural enemies within target release area. Determine if additional releases are necessary.	X		Several new exotics have persisted over several years and are multiplying and spreading in Texas and California.
Systematics, ecology, and population dynamics of natural enemies:[b]				
Clarify sytematics of predators, parasitoids and pathogens.	Provide taxonomic support for importation and mass-rearing programs. Publish keys to assist in species identifications.	X		Key on exotic *Eretmocerus* published. Program developed for curating, cataloging recovered parasitoids.
Determine *Bemisia*- natural enemy-host plant (Tritrophic) interactions.	Study plant characteristics mediating whitefly and natural enemy population densities.	X		Parasitoid foraging, oviposition varied in response to different plants (crops) and host whitefly. Plants varied in color, architecture, and semiochemicals.
Identify the attributes of natural enemy biology and population level interactions to explain biological control successes and failures.	In conjunction with field evaluations, validate predictions made by behavioral and population models important to biological control.	X		No interference competition measured, with respect to whitefly control, when mixing primary parasitoids and autoparasitoids.

[a] See Table C for complementary research.
[b] See Table A for complementary research.

Table D. Natural Enemy Ecology and Biological control.

Research Approaches[a]	Year 3 Goals Statement	Progress Achieved Yes	No	Significance
Natural control and conservation:				
Develop natural enemy conservation practices to reduce mortality to indigenous and introduced natural enemies.	Conduct manipulative experiments to evaluate the impact of each natural enemy mortality agent on whitefly suppression.	X		Life history tables have been constructed comparing mortality factors of natural enemies in conventional vs IGR treated cotton. Functional response data available for several parasitoid species.
Evaluate potential of alternate plants to act as in-field refuges or insectaries for natural enemies.	Conduct field tests to assess whether refuges act of natural enemy and whitefly sinks or sources to adjacent cropping systems.	X		Research in the Imperial Valley has shown that perennial refuges support large numbers of whitefly and parasitoids that migrate to adjacent systems.
Assess cues used by natural enemies to locate whitefly and to identify potential methods for enhancing natural enemy activity.	Conduct small scale trials to enhance whitefly suppression by manipulating natural enemy location and attack of whitefly.		X	
Augmentation of natural enemies:				
Develop natural enemy mass-rearing systems.	Develop rearing systems on selected hosts and on artificial diets. Determine economic feasibility of the procedure.	X		Mass rearing methods on SLWF has been accomplished. Artificial diets are still being researched, with economics undetermined.
Develop release technologies to maximize the effectiveness of mass-reared natural enemies in the field.	Develop necessary technology for release of the appropriate natural enemy life stage.	X		Several release technologies have or are being tested. Banker plant technology appears to be very effective. Capsule delivery methods being tested. Cold storage of parasitoid pupae also being tested
Evaluate augmentative parasitoid, predator, or pathogen releases.	Identify optimal release strategies for key cropping systems.	X		Parasitoid release rates have been determined for major crops. Strategies for releasing/integrating parasitoid and predator in greenhouse crops have been determined. Significant information currently available on application of fungal pathogens in various crops.

Table D. Natural Enemy Ecology and Biological Control. (continued)

Research Approaches[a]	Year 3 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Importation biological control:				
Evaluate the ability of exotic natural enemies to suppress whitefly populations under field conditions.	Assess spread of established natural enemies and their ability to suppress whitefly populations	X		Whitefly suppression by exotic parasitoids determined by multiple researchers. Preliminary data suggests significant spread of established exotic parasitoids in some regions. Dispersal rates of natural enemies still under study.
Systematics, ecology, and population dynamics of natural enemies:[b]				
Clarify sytematics of predators, parasitoids and pathogens.	Provide taxonomic support for importation and mass-rearing programs.	X		Several taxonomic keys developed for imported parasitoid species. RAPD-PCR techniques proven as quick identification method. Preliminary Satellite DNA techniques proven, however, still under development.
Determine *Bemisia*- natural enemy-host plant (Tritrophic) interactions.	Study compatibility of characteristics of plant traits mediating whitefly populations with the abilities of natural enemies to suppress whitefly populations.	X		Tri-trophic interactions determined for *B. bassiana* / SLWF / tomato. Some research completed on parasitoid / host / plant interactions.
Identify the attributes of natural enemy biology and population level interactions to explain biological control successes and failures.	Assess deviations between theoretical predictions and field data.	X		Some life history data collected on parasitoid and predator populations in cotton. BioControl-Parasite simulation model available for testing / validation. Some Laboratory data available for testing theoretical predictions of field level performance.

[a] See Table C for complementary research.
[b] See Table A for complementary research.

Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions
Co-Chairs: Cindy McKenzie and Greg Walker

Investigator's Name(s): James S. Buckner[1], Thomas P. Freeman[2], & Dennis R. Nelson[1].

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Research & Implementation Area: Section E: Host Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

Dates Covered by the Report: 1999

The Physiology of the Whitefly Egg Pedicel

Bemisia argentifolii Bellows and Perring (Homoptera: Aleyrodidae) eggs oviposited on artificial membranes of stretched Parafilm M® were used to study the function of the egg pedicel as an essential interface between the host plant and subsequent nymphal development and hatch. Feeding females oviposited eggs on membranes covered with a media consisting of 20% sucrose. After oviposition, the media was removed, the membrane surface with exposed egg pedicels was rinsed three times with sterile deionized water, and residual water removed by blotting with a dry tissue. For experimentation, the pedicels of oviposited eggs were submersed in test solutions, placed in a desiccator cabinet and held at 25°C and a relative humidity (rh) of 95-100%.

To demonstrate media uptake by *B. argentifolii* eggs, the pedicels of the eggs oviposited on membranes were exposed to [^{14}C]-inulin (12.6 dpm/nl) diluted in 7.5% sucrose. After exposure to label for 48 hr, portions of membranes containing eggs and no eggs (controls) were suspended in 0.5 ml water. The suspension was frozen by submersion in a bath of dry ice/ethanol, thawed, sonicated, diluted to 7 ml with scintillation fluid and assayed for radioactivity using a scintillation counter. In two experiments with 69 and 127 *B. argentifolii* eggs, label uptake per egg was 7.6 dpm or approximately 0.6 nl. Since inulin is a polysaccharide that cannot cross a biological membrane, it was assumed that the labeled inulin resided within the pedicel of the egg and not within the developing embryo. Radiolabeled sodium acetate was used to demonstrate egg pedicel uptake of a chemical into the egg. *B. argentifolii* eggs were exposed to radiolabeled acetate in 7.5% sucrose for 48 hr and then at 95-100% rh until nymphal hatch. The resulting hatched nymphs were collected, digested in tissue solubilizer and assayed for ^{14}C. In three experiments with 198, 290 and 503 eggs on membranes, egg hatch ranged from 91-100% and uptakes of ^{14}C in dpm/nymph were 339, 349 and 672, respectively. Factoring in the concentration of [^{14}C]-acetate in the media, the uptake volumes in nl/nymph were 1.6, 0.8 and 1.8, respectively. Thus, our experiments demonstrated that *B. argentifolii* eggs use their pedicels to transport water and solutes from the media into developing nymphs.

To demonstrate that *B. argentifolii* eggs require water for normal embryonic development and nymphal hatch, the pedicels of eggs on membranes were exposed to environments at various levels of relative humidity. Egg laden membranes (65-256 eggs per membrane) were incubated at 25°C for 7-8 days and percentage values for egg hatch were determined. At humidity ranges of 0-20% rh, 55-65% rh and 75-85% rh, none of the eggs hatched. At 95-100% rh, the mean percentage hatch value for five membranes with 109-242 eggs/membrane was 95.0 ± 5.2. Two membranes were used as controls (where the pedicels were in contact with sterile water) and the percentage hatch values for 152 and 184 eggs were 86.8 and 98.3, respectively. These results using humidity and radiolabeled materials strongly suggest that whitefly egg hatch is dependent upon water uptake from the host plant either in the form of free water or very humid air.

Transmission electron microscopic (TEM) and scanning electron microscopic (SEM) techniques were used to examine the structure of the *B. argentifolii* egg pedicle. SEM analyses of mature eggs removed from ovaries of females revealed that the surfaces of the distal portion of the pedicel consisted of a tangled array of fibers. TEM analyses of cross-sectional and longitudinal views of pedicels from mature eggs indicated that about 20-25% of the outer diameter of the distal portion of the pedicel was made up of the fibrous material. The arrangement of the fibers and the nature of their connection to the core of the pedicle were suggestive that the fibers function as the collector and conduit for water (vapor), and perhaps solute, movement into the egg.

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Research & Implementation Area: Section E: Host Plant Resistance, Physiological Disorders, and Host Plant Interactions.

Dates Covered by the Report: 1999

Analysis by DC Electrical Penetration Graphs of the resistance to *Bemisia tabaci* (Homoptera: Aleyrodidae) on two near-isogenic tomato lines

The tomato *Mi* gene confers resistance to nematodes, *Meloidogyne* spp., and to the potato aphid, *Macrosiphum euphorbiae* (Thomas). Previous greenhouse choice assays with *Bemisia tabaci* (Gennadius) showed that tomato varieties carrying this gene had significantly ($P<0.05$) lower values of host suitability and whitefly reproduction than varieties lacking *Mi*. This indicated that *Mi*, or another gene in its region, could regulate partial resistance. In order to characterize this resistance, the probing and feeding behavior of *Bemisia tabaci* B-biotype were studied with a DC Electrical Penetration Graph (EPG) on the near-isogenic tomato lines Moneymaker (without *Mi*) and Motelle (carrying *Mi*). Significant differences ($P<0.05$) between tomato lines were found in EPG parameters related to plant surface/epidermis and/or mesophyll tissues: number of probes made before attaining the first phloem phase (i.e., salivation and/or ingestion in a sieve element); the ratio: (number of probes made before first phloem phase)/(total number of probes); total duration of non-probing time (i.e., stylets not in plant); time it took for the whitefly to make its first intracellular puncture (stylet penetration to the phloem is mostly intercellular); time it took to reach the first phloem phase; and percentage of whiteflies that reached phloem phase. On Motelle, a lower percentage of whiteflies achieved phloem phase and they made more probes, had a higher ratio (number of probes before first phloem phase)/(total number of probes), had a longer total duration of non-probing time, and a longer time before making the first intracellular puncture and the first phloem phase. In contrast, most of the parameters related to phloem phase (for example, the total duration of phloem phase, the total duration of salivation in a sieve element, the total duration of ingestion from a sieve element) were not found to significantly differ between these near-isogenic lines. These data suggest that some resistance factors might be present in the plant surface/epidermis and/or mesophyll layers of Motelle plants, which may be regulated by the *Mi* gene or another gene in its region. Further studies are necessary to provide a better understanding of these mechanisms of resistance to whiteflies in tomatoes.

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Research & Implementation Area: Section E: Host Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

Dates Covered by the Report: 1999

Screening Cantaloupe Varieties for Whitefly Resistance

Silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring, continues to be the most important pest insect for cucurbits, particularly on cantaloupe, in south Texas. The objectives of this study were to develop a rapid method to screen varieties, lines and PIs of cantaloupe for whitefly resistance; to determine the resistant mechanism of some whitefly resistant and susceptible varieties under laboratory and greenhouse conditions by studying the oviposition, development, survivorship and reproduction on each variety. A tuning table was used. The table can be easily turned around after the insects on the plants are counted. Six varieties and lines were used in this study: Hymark, Tam Sun x gl, Explorer, Tam Sun, Primo, and Perlita. Whitefly adults used in this study were cultured on cantaloupe and other crops in a greenhouse. When the plants for each variety or line grew up to 7-8 leaves, 2 fully expanded leaves (the 3rd and the 6th leaf from the terminal) were used for each plant, and the terminal and other leaves were removed. A turn-table, 2 ft in diameter, made of polywood, were used to hold 6 pots of melon plants, each representing a variety or line. The table with the 2-leaf plants were confined inside a cage. Whitefly adults were introduced into the cage at a rate of 50 adults per plant (leaf). The number of whitefly adults on each leaf were counted in 4 and 24 h after the whitefly introduction. Because the whiteflies are aggregated between and within plants, the location of the plant inside the cage may influence the number of whiteflies on it. To avoid this bias, the leaves with the whiteflies were disturbed after the number of adults was counted to allow the whiteflies to relocate their feeding or ovipositing site. The table were turned around, and the plants were relocated randomly. The number of whitefly eggs on each leaf were counted 24 h after the adult introduction. The leaf area was measured, and the number of whitefly eggs and adults on each leaf was computed. Trichome density of the selected leaves (2 per plant) were measured by laying 2 1-cm^2 templates over the adaxial surface of the leaves, 1 on each side of the main vein, and the number of trichomes were counted with the perimeter of the template. On a precision balance, all sample leaves were weighed individually. After counting the whitefly eggs and trichomes on the leaves, the leaf thickness was measured. Leaf area was then measured using a portable area meter. Ten to twenty cantaloupe plants form each variety, one per pot, were maintained on a bench in a greenhouse. The plants were used for experiment when the leaves are 30-40 cm^2. A leaf clip on cage was placed on a fully expanded leaf, and 20 whitefly females (<24 h old) were introduced inside the cage. Adults were removed 4 h after the introduction. Eggs on the leaf were marked and coded. The eggs were monitored daily for hatching. After the first instar crawler hatches, the development of each nymphal stage was monitored daily until the adult emerges. To determine the effects of variety to whitefly reproduction, the newly emerged adults were collected, and the adults were sexed, and the mated females were caged on the leaves of the same variety and another variety with different resistant characteristics. Oviposition were checked in 2-3 days.

Number of silverleaf whitefly adults on different varieties in 2, 4 and 24 hours varied greatly, but did not show significant differences. Significantly fewer eggs were found on Tam Sun and Tam Sun x gl. than on any other varieties. Silverleaf whitefly developed significantly different on different varieties. Whitefly eggs developed longer on Hymark than on all other varieties. Whitefly nymphs developed significantly longer on Tam Sun and Hymark, followed on Tam Sun x gl. (glabrous). In contrast, whitefly pupae on Tam Sun x Glabrous developed significantly slower than on Tam Sun and Primo, but not slower than on Hymark, Explorer, and Perlita. The overall developmental durations of all immature stages were significantly longer on Tam Sun, Hymark and Tam Sun x gl. than on other three varieties. Natural percentage mortalities of silverleaf whitefly from egg to adult emergence varied greatly among the varieties with 60% mortality on Hymark; whereas those on other varieties were not significantly different.

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Research & Implementation Area: Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

Dates Covered by the Report: 1999

Effect of Plant Growth Promoting Rhizobacteria on Pathogenesis-Related Protein Induction in Cucurbits Challenged with Different Levels of SLWF Infestation

Two lab trials were conducted sequentially to evaluate SLWF preference for two different cucurbit hosts (watermelon and cantaloupe) treated with eight different plant growth-promoting rhizobacteria (PGPR) and the subsequent effect on Pathogenesis-Related (PR) protein induction.

Watermelon seeds cv. 'Star gazer' were direct seeded into speedling trays and allowed to germinate. PGPR were applied to the potting mix as a gram positive dry spore formulation. When seedlings reached the 2-3 true leaf stage they were individually transplanted into 12 oz solo cups with Metro Mix 500, fertilized with a dilute Peter's solution 20-10-20 at 5 ml per plant and allowed to acclimate for 72 hr. Five plants per replicate were arranged in a RCB design with each replication housed in a separate 24"x 24"x 24" Plexiglas cage. The first two fully expanded leaves from 3 plants per treatment were sampled for PR protein analysis prior to SLWF infestation. Five SLWF adults per plant were released in each cage and the total number of SLWF eggs, nymphs and adults were counted on the third fully expanded leaf from the terminal 7 days after infestation. The first two fully expanded leaves from the same plant used for SLWF counts were sampled for PR protein analysis immediately prior to insect counts taken that same day.

The second lab trial was similar to the first with the following exceptions. Cantaloupe cv. 'Athena' were at the 3-4 true leaf stage before being individually transplanted. Infestation level and infestation period were doubled to 10 SLWF adults per plant and 14 days, respectively. Leaf area was calculated for the leaf used for insect counts. PR protein leaf samples were sampled prior to infestation and immediately before insect counts at 14 days.

SLWF preferred to oviposit on PGPR treated watermelon and cantaloupe compared to the untreated control by at least two to one depending on treatment. SLWF nymph counts followed the same trend, but were more variable. Adult whiteflies preferred PGPR treated plants 4- and 8-fold more to the untreated for watermelon and cantaloupe, respectively. However, there was a positive correlation between leaf area and SLWF numbers detected for cantaloupe indicating preference may be due to leaf size as a result of the PGPR treatment.

In watermelon, total protein concentrations were higher in preinfested plants. The reverse was true for cantaloupe with infested leaves having 1.8-fold higher total protein concentrations even though the infestation time and level was doubled. PR proteins analyzed included chitinase, glucanase and peroxidase. No significant treatment interactions could be detected among the PGPR treatments. Only the date interaction was significant indicating that SLWF infestation was more effective in inducing PR proteins than PGPR treatments when proteins were induced. No differences between dates for total chitinase could be detected for watermelon or cantaloupe. Total chitinase per leaf was 1.7-fold higher in preinfested leaves for watermelon and in contrast infested cantaloupe leaves were 1.7-fold higher. Total glucanase was 1.6-fold higher in infested watermelon leaves than preinfested, but no differences between dates for total glucanase per leaf could be detected for watermelon or cantaloupe. In cantaloupe, total peroxidase and peroxidase per leaf was 6- and 3-fold higher in preinfested leaves compared to infested. However, the reverse was true for watermelon. Infested leaves were 14- and 10-fold higher for total peroxidase and peroxidase per leaf respectively in infested watermelon leaves. Studies are ongoing to elucidate the sharp contrasts found for these two cucurbits.

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Research & Implementation Area: Section E: Host-Plant Resistance, Physiological Disorders and Host Plant Resistance.

Dates Covered by the Report: March 1999 - December 1999

Normal Leaf and Okra-Leaf Upland Cotton Cultivars Susceptibility to Infestation by Silverleaf Whitefly

Sixteen upland cotton, *Gossypium hirsutum* L., cultivars and experimental breeding-lines were evaluated in the field for susceptibility to silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring, sown at the UC Desert Research & Extension Center, Imperial Valley, CA, into plots of a randomized complete block design experiment replicated four times, and irrigated 26 March, 1999. The normal leaf cultivars were DP 20, DP 50, DP 90, DP 5415, DP 5432, DP 5461, DP 5557, HCR 9257, HCR 9240, HCR 7126, and, Stoneville 474 and the okra-leaf cultivars and experimental breeding-lines were Siokra L23, , FiberMax 832, CSIRO 91209-194, and CSIRO 89230-244-1028. Individual plots measured 14 m in length with 8-beds on 1 m centers or 8m wide. No insecticides were applied to the cotton plots. Silverleaf whitefly adults were sampled from ten plants at random in each plot via the leaf turn method using the 5th main stem leaf from the terminal on 27 May, 3, 25, 30 June, 7, 14, 20, 28 July, 4, 11, 18, & 25 August, 1999 Silverleaf whitefly nymphs were counted on 1.65 cm^2 leaf disks of from ten 5th position leaves down from the terminal extracted from randomly selected plants in each plot on 30 June, 7, 14, 20, 28 July, 4, 11, 18, & 25 August. Seed cotton was hand picked from 0.002 acre per plot and yield data were recorded on 10 September, 1999. The okra-leaf entries as a group had fewer silverleaf whitefly adults and nymphs than the normal leaf cotton entries. The okra-leaf experimental breeding-lines CSIRO 91209-194, and CSIRO 89230-244-1028 had the lowest numbers of silverleaf whitefly adults and nymphs among the okra-leaf entries. Stoneville 474, a hirsute-leafed cotton, had the greatest numbers of silverleaf whitefly adults and nymphs among the normal leaf cottons. There were no differences in seed cotton yield among the entries, $P \leq 0.05$, SNK.

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Research & Implementation Area: Section E: Host-Plant Resistance, Physiological Disorders, and Host Plant Resistance.

Dates Covered by the Report: March 1999 - December 1999

Resistance To Cotton Leaf Crumple Geminivirus Disease In Upland Cotton

Eight upland cotton, *Gossypium hirsutum* L., cultivars or experimental breeding-lines were evaluated in the field for resistance to the silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring, transmitted cotton leaf crumple disease caused by cotton leaf crumple geminivirus (CLCV) in Imperial Valley, CA in 1999. The cultivars were Texas 121, AP 4103, AP 6101 and Stoneville 474 and the breeding-lines were DG 2165 and DG 2108 and with Cedix parentage were DG 2383, and DG 2387. The following rating scale for CLCr disease symptom was used on 23, 27 and 30 August and on 6 September: 1 = leaf smooth, few if any bumps or blisters; 2 = some obvious blisters and crumpling, but less than 50% leaf with symptoms; 3 = obvious crumpling, blisters, vein clearing from more than 50% to close to 100%, leaf not rolled; 4 = severe crumpling, blisters, leaves noticeably rolled and distorted. Leaf and petioles from each plot were used to confirm the presence of CLCrV by squash blot hybridization with a general DNA probe, which detects the presence of whitefly-transmitted geminiviruses (Gilbertson et al. 1991). DNA sequencing of a polymerase chain reaction (PCR) amplified fragment from an infected plant was used to confirm that the geminivirus was CLCrV.

Cotton cultivars and breeding-lines were evaluated in 1999 in Imperial Valley, California for resistance to the silverleaf whitefly-transmitted cotton leaf crumple disease, caused by cotton leaf crumple geminivirus (CLCV). Results showed differences in whitefly infestation levels and virus disease symptoms among cotton entries. The variety Stoneville 474, with hirsute leaves, had more adult silverleaf whitefly for the seasonal mean than any of the other entries, (SNK; P# 0.05). Seasonal silverleaf whitefly nymphs per cm^2 mean separations were as follows: Stoneville 474 (15.1 A), DG 2108 (8.7 B), DG 2387 (5.4 C), Texas 121 (5.3 CD), AP 6101 (5.1 CDE), AP 4103 (4.9 CDE), DG 2383 (3.8 DEF), DG 2165 (3.5 F). (The breeding-line with Cedix parentage had a lower CLCV disease rating than other entries; DG 2165 (1.5), DG 2108 (1.4), DG 2383 (1.1), and DG 2387 (1.1). Varietal CLCV disease rating were as follows: Texas 121 (2.1) < Stoneville 474 (2.5) < AP 6101 < AP 4103 (3.6). Seed cotton yield as pounds per acre and mean separations were as follows; AP 6101 (2743 A), AP 4103 (2455 AB), DG 2383 (2301 AB), DG 2165 (2014 BC), Texas 121 (2001 BC), DG 2387 (1900 BC), DG 2108 (1616 CD), and Stoneville 474 (1250 D).

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Dates Covered by the Report: July - December 1999

Host Plant Preference and Performance of *Bemisia argentifolii (*Homoptera: Aleyrodidae) on Poinsettia (*Euphorbia pulchirrima)* in Relation to Cultivar

We investigated the resistance qualities of seven economically important red cultivars of poinsettias against its major pest, the silverleaf whitefly, *Bemisia argentifolii*, Bellows and Perring. Additionally, two cultivars selected on the basis of previous adult preference studies (representing preferred and non-preferred) were monitored for nymphal development and survivorship. After 6 d of exposure, the cultivars "Red Velvet", "Supjibi", and "Pepride" were less preferred as oviposition sites than the other 4 cultivars evaluated. "Peterstar" was the most preferred host for oviposition. After 21 days of exposure, there were significantly fewer eggs and nymphs observed on "Pepride" and "Red Velvet" and "Peterstar" again had significantly more eggs than the other preferred cultivars. "Success" and "Petoy" had a significantly greater numbers of surviving nymphs than the other cultivars evaluated. Total numbers of all live stages observed were significantly lower on "Freedom Red", "Red Velvet" and "Pepride". These latter cultivars demonstrated the greatest potential for resistance against the silverleaf whitefly. Observed plant morphology in addition to plant chemistry may explain the differences in suitability among the poinsettia cultivars. The population dynamics of silverleaf whiteflies on the most preferred and non-preferred poinsettia hosts are represented as life tables. The wider implications of the mechanisms of poinsettia resistance to whiteflies and future uses in integrated pest management for greenhouse cropping systems will be discussed.

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Research & Implementation Area: Section E: Host Plant Resistance, Physiological Disorders, and Host-Plant Interaction.

Dates Covered by the Report: January 1999 - January 2000

Characterization of Two Squash Genes Induced by Silverleaf Whitefly Infestation

Squash genes induced in apical, silvered leaves after silver-leaf whitefly (*Bemisia argentifolii*) feeding were isolated. SLW1 and SLW3 were differentially expressed by *B. argentifolii* and the sweetpotato whitefly (*B. tabaci*). SLW1 and SLW3 RNAs accumulated locally and systemically after nymph feeding. SLW1 RNAs were detected in infested leaves, distal, apical leaves and the shoot apex in *B. argentifolii*-infested plants but was not induced after *B. tabaci* feeding. SLW3 RNAs accumulated in infested leaves and in proximal non-infested leaves from *B. argentifolii* and *B. tabaci*-infested squash. SLW3 RNAs accumulated in more distal leaves only in response to *B. argentifolii*. SLW1 RNAs were detected in flowers and fruit, while SLW3 RNAs were not detected in any organ other than leaves. Whitefly feeding did not alter this developmental programming. SLW1 (a M20b peptidase-like gene) and SLW3 (a β-glucosidase-like gene) are modulated by different signal transduction pathways. SLW1 RNAs and proteins were abundant in response to exogenous methyl jasmonate (MeJA) and water-deficit stress. SLW1 RNAs were detected at low levels after wounding, *Pseudomonas syringea* pv *syringea* infection and ABA or ethylene treatments. Like SLW1, SLW3 RNAs accumulated to high levels in response to water-deficit stress. However, SLW3 RNA levels were not influenced by pathogen infection, wounding, MeJA, ethylene, salicylic acid, or ABA treatments. Possible roles for SLW1 and SLW3 are discussed. (Supported by USDA 95-37301-2081 to TMP and LLL and USDA 99-35301-8077 to LLW)

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Research & Implementation Area: Section E: Host Plant Resistance, Physiological Disorders, and Host Plant Interactions

Behavioral Response of Silverleaf Whitefly Adult Females to Plant Species Varying in Host Suitability

The behavior of adult female silverleaf whiteflies on four plant species, lima bean, broccoli, corn, and sugar beet, was studied by making visual observations of individual whiteflies on these plants. The plants were chosen to represent a range of host suitability for silverleaf whitefly from excellent to poor host. This study is part of a larger project whose objective is to determine how whiteflies distinguish among plant species of different host suitability. In relation to host plant resistance, there are few cases of a single crop species having different varieties whose host suitability to silverleaf whitefly ranges from highly susceptible to highly resistant. Consequently, to study a range of plants that include these extremes, we used four different plant species.

First, we verified that these plant species represent a range from very suitable to very poor hosts. Adult female whiteflies were confined singly in clip-on cages to leaves of young plants (< 1 month old) for 2 days on each of the four plant species. Whiteflies used in the experiments were reared on lima bean, and had not been exposed to the other plant species prior to the experiment. Mortality over the 2 day period increased from lima bean (8% mortality), to broccoli (16% mortality), to corn (36% mortality), to sugar beet (62% mortality). Mortality on sugar beet was significantly higher than on lima bean and broccoli ($P < 0.05$, chi-squared test), whereas mortality on corn was significantly higher than on lima bean but not significantly higher than on broccoli. Whitefly fecundity over the 2 day period (calculated only for females that survived the 2 day period) was significantly higher on lima bean and broccoli (17-20 eggs per female, respectively) than on sugar beet and corn (6-10 eggs per female, respectively). We conclude that lima bean and broccoli are good hosts for silverleaf whitefly; sugar beet is a very poor host, and corn is a moderately poor host. These results were expected because 1) the whiteflies were reared on lima bean; 2) silverleaf whitefly is well documented to build large populations on broccoli; and 3) silverleaf whitefly is rarely considered pests of sugar beet and corn even though both crops are grown in areas with high populations of silverleaf whitefly.

Using a stereo-microscope focused on the underside of a leaf held at a 45 degree angle, continuous behavioral observations were made during the first 15 minutes of whitefly contact with the leaf. The sequence and duration of the following behaviors were recorded: labial dabbing (rubbing the apex of the labium over the leaf surface), probing (stylet insertion, indicated by the labium being held motionless with its apex contacting the leaf surface at a right angle), and oviposition. If the whitefly was probing at the end of the standard 15 minute observation period, observations were continued until either the whitefly terminated the probe or until the probe exceeded 15 min in duration, whichever occurred first. Thus, the maximum probe duration that could be recorded was 15 min. Labial dabbing was selected as a relevant host selection behavior because previous work in our lab indicated that the whitefly labium has mechanoreceptors and chemoreceptors at its apex.

Two hundred and ten probes were observed among the 4 plant species, and all 210 were preceded by labial dabbing. The duration of labial dabbing preceding the first probe differed little among the 4 plant species. The first bout of labial dabbing on lima bean was slightly, but significantly, shorter than on corn (2.7 versus 3.6 sec) while the duration of the first bout of labial dabbing was intermediate on broccoli and sugar beet. It is questionable whether this small difference is biologically significant or only statistically significant. The time it took to initiate the first probe did not differ significantly among plant species (range: 6.2 - 8.1 sec). The duration of the first probe also did not differ significantly among the 4 plant species (range: 580 - 391 sec); however when all probes were taken into consideration, average probe duration was significantly longer on lima bean than on the other 3 plants. Oviposition occurred for 8/23 whiteflies on lima bean, 13/23 whiteflies on broccoli, 2/24 whiteflies on corn and 9/21 whiteflies on sugar beet. For those whiteflies that oviposited, the average time to oviposition did not differ among the 4 plant species and ranged from 454 to 657 seconds from the beginning of observations. Calculated from the beginning of the probe in which oviposition occurred, the time to oviposition again did not differ significantly among plant species and ranged from 163 to 463 seconds. It is noteworthy that this is not enough time for the whitefly to reach the phloem. Thus, these results agree with our previous study on electronically monitored whiteflies that after first encounter with a new plant species, the great majority of the first eggs laid by silverleaf whiteflies are oviposited before the whitefly can test the phloem for suitability.

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Research & Implementation Area: Section E: Host Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

Dates Covered by the Report: January 1999 - January 2000

Whitefly Feeding Induces Local and Systemic Changes in Tomato Gene Expression

Whitefly infestations of crops across the Southern United States and throughout the world results in millions of dollars in damage each year. Not only do whiteflies remove photo-assimilates and vector and array of devastating viruses, but they also cause developmental disorders in plants such as squash, broccoli, and tomato. Many preceding studies have focused on the plant defense responses to chewing insects. In this report, the tomato response to phloem-feeding whiteflies (*B. argentifolii* and *T. vaporariorum*) is characterized. RNA blot analysis using defense-regulated gene probes have shown that whitefly feeding induces the accumulation of pathogenesis-related protein (PR) gene transcripts. The basic PR gene RNAs, such as basic glucanase and basic chitinase, accumulate to high levels nine days after whitefly feeding. In contrast, low levels of acidic PR gene RNAs were detected. These data indicate that the salicylic acid-independent pathway is strongly induced, while whitefly feeding induces the SA-dependent pathway weakly. The levels of SA were monitored for 9 days following whitefly feeding; SA concentrations did not increase significantly following whitefly feeding. Wound-response genes regulated by the octadecanoid pathway, such as LapA and pin2 genes, were not expressed following whitefly feeding at the level of RNA blot analysis orbe analysis of transgenic LapA:GUS tomato plants. These studies indicate that tomato plants perceive phloem-feeding silverleaf and greenhouse whiteflies in a manner distinct from that of chewing insects.

Research Summary

Section E. Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

Compiled by Greg Walker & Cindy McKenzie

Advancements continue to be made in several areas of study: breeding/screening plants for resistance to whitefly and whitefly-transmitted viruses; evaluation of whitefly susceptibility/resistance among plant species; mechanisms of plant resistance to whiteflies; physiological interactions between whiteflies and plants; plant molecular response to whitefly feeding; whitefly feeding behavior; and effect of natural plant products against whiteflies.

Breeding/Screening Plants for Resistance to Whitefly and Whitefly-Transmitted Viruses.

Cantaloupe. Six cantaloupe varieties were screened for resistance against silverleaf whitefly in laboratory and greenhouse tests: Hymark, Tam Sun, Tam Sun x glabrous, Explorer, Primo, and Perlita. Scored on the basis of oviposition and development rate, Tam Sun, Tam Sun x glabrous, and Hymark appeared to be more resistant than the other varieties.

Poinsettia. Seven varieties of poinsettia were evaluated for their relative resistance against silverleaf whitefly. The varieties "Red Velvet" and "Pepride" consistently ranked among the most resistant cultivars based on numbers of whitefly eggs, nymphs and immature survival. The variety "Freedom Red" also appeared to be relatively resistant. The varieties "Peterstar" and "Petoy" were the most susceptible varieties.

Alfalfa. Studies were initiated to quantify the degree of whitefly resistance in vegetatively-propagated clones of plants chosen from the fifth year of a field selection program for developing silverleaf whitefly resistance in alfalfa. Plants that had low whitefly density in the field were chosen as "presumed-resistant" plants; whereas plants that had high whitefly density in the field were chosen as "presumed-susceptible" plants. Clonal propagation of plants allows replicated trials on individual genotypes. Fecundity of an alfalfa-reared population of silverleaf whiteflies on presumed resistant alfalfa plants was 69% of that on presumed susceptible plants. Fecundity of a cotton-reared population of silverleaf whiteflies on presumed resistant alfalfa plants was 57% of that on presumed susceptible plants.

Cotton. Upland cotton cultivars and breeding lines were evaluated for resistance to silverleaf whitefly and for resistance to the silverleaf whitefly-transmitted geminivirus, cotton leaf crumple, in replicated field trials in the Imperial Valley, California. In the first study, there were 12 normal leaf entries and 4 okra leaf entries. The okra leaf varieties had fewer whitefly nymphs and adults than the normal leaf varieties. Among the normal leaf varieties, one variety was very hirsute (Stoneville 474) while the other 11 were more-or-less glabrous. The hirsute variety had the most whitefly adults and nymphs. In the second study, there were 8 cultivars and breeding lines. Whitefly densities and cotton leaf crumple severity both differed significantly among the entries. A hirsute variety (again, Stoneville 474) had the highest densities of whitefly adults and nymphs. DG 2383 and DG 2165 had the lowest whitefly numbers. The breeding lines with Cedex parentage (DG 2383 and DG 2387) had the lowest severity of cotton leaf crumple. Whitefly density and disease rating were not significantly correlated.

Tomato. In Israel, the tomato variety TY172 was shown to be resistant to tomato yellow leaf curl virus (TYLCV), a geminivirus transmitted by *Bemisia* whiteflies. Resistance is manifested by lack of symptoms and failure to accumulate high virus titers even when plants are continuously exposed to very high levels of virus. Experiments were conducted to determine the ability of whitefly vectors to acquire TYLCV from tomato variety TY172, two other virus-resistant varieties, and from a virus-susceptible variety. After a 48 h access period on the virus source plants, whiteflies were transferred to healthy susceptible plants, a single whitefly per plant. Virus transmission was highest (59%) for whiteflies that acquired virus from the susceptible plants, and lowest (17%) for whiteflies that acquired virus from TY172. It was concluded that TY172 is a symptomless carrier of TYLCV whose low virus titers make it a relatively poor source of virus for inoculating susceptible tomato varieties.

Evaluation of Whitefly Susceptibility/Resistance Among Plant Species.

Developmental rate, fecundity, longevity, and sex ratio of *Bemisia tabaci* were compared among five major crops in India: cassava, sweet potato, cotton, eggplant, and tobacco. The first study (at 30 degrees C) compared sweet potato, cotton, and cassava. Duration of the life cycle ranged from 19.5 days on sweet potato to 23.5 days on cassava. Female longevity ranged from 13 days on cotton to 18 days on cassava. Mean total fecundity was similar among the three plant species, ranging from 41 - 45 young per female, and sex ratio (male:female) also was similar among the three plant species, and slightly female-biased, ranging from 1:1.2 to 1:1.8. The second study compared cotton, egg plant, and tobacco. In this study, duration of the life cycle was similar among the three plant species, and ranged from 17-23 days.

In South Carolina, five medicinal plant species were compared for their relative susceptibility to silverleaf whitefly. The plants were feverfew, St. John's wort, common valerian, and two species of purple coneflower (*Echinacea pallida*, and *E. purpurea)*. Silverleaf whitefly completed development on all 5 plant species. In the field, *E. purpurea* harbored the highest whitefly

populations, and in laboratory choice and no-choice tests, *E. purpurea* was again implicated as the preferred host of these 5 plant species.

The behavior of adult female silverleaf whiteflies on four plant species, lima bean, broccoli, corn, and sugar beet, was studied by making visual observations of individual whiteflies on these plants. The plants were chosen to represent a range of host suitability for silverleaf whitefly from excellent to poor host. Data on the fecundity and survivorship of adult females on these plant species indicated that lima bean and broccoli were very good hosts, corn was a moderately poor host, and sugar beet was a very poor host. Despite the wide range in host suitability represented by these four plant species, behavior of adult females on these four plants was similar during the first 15 min of contact with the plant. After first contacting the plants, whiteflies initiated probing in a similar amount of time (mean ≈ 7 sec) on the 4 plant species, and the mean duration of the first probe was similar among the 4 plant species (5.2 - 8.8 min). All probes on all plant species were preceded by a brief period (6-16 sec) of "labial dabbing" behavior, where the apex of the labium, with its mechano- and chemoreceptors, is rubbed over the leaf surface. Eggs were laid during the 15 min observation period on all 4 plant species, although at a lower rate on corn (only 2/24 whiteflies oviposited) than on the other 3 plant species (8/23 whiteflies oviposited on lima bean, 13/23 on broccoli, and 9/21 on sugar beet). The first oviposition in all plant species occurred before there was sufficient time to reach the phloem.

Three studies evaluated different plant species for their role as reservoirs of silverleaf whiteflies that can be a source of whiteflies for infesting susceptible crop species. In California's San Joaquin Valley, citrus adjacent to cotton fields has been implicated as an important overwintering host for silverleaf whiteflies during the time of year when there is no cotton in the ground. However, egg-to-adult survivorship on citrus was very low (0.7 - 3.7% in the winter of 1997-98, and 0.04 - 0.38% in the winter of 1998-99). Few whiteflies reproduce in citrus during the summer months. Thus, citrus appears to be a poor host for silverleaf whitefly, although citrus may be important for overwintering parasitoids as the few whiteflies found on citrus were heavily parasitized. A survey of weeds in citrus orchards suggests that weeds could be important overwintering hosts for silverleaf whitefly, as well as for its parasitoids. In a different plant survey in the southern San Joaquin Valley, 334 plant species have been examined since 1991 to determine whether or not they are host plants of silverleaf whitefly. Two hundred and forty two of these plants (72%!) were determined to be host plants by the criteria of containing eggs, nymphs, and pupal exuvia of silverleaf whitefly. The number of species of host and non-host plants for different plant categories were: agronomic crops, 11 host & 7 non-host species; vegetable crops, 47 & 4; ornamental plants, 106 & 72; fruit trees, 18 & 5; and weeds, 60 & 6. Of the 242, host plants, 149 of them were overwintering hosts. The wide host range provides a continuity of year-round host plants for silverleaf whitefly.

Mechanisms of Plant Resistance to Whiteflies.
Field trials to evaluate upland cotton cultivars and breeding lines for resistance to silverleaf whitefly (described in more detail, above) provided evidence on the role of three plant morphological characteristics in resistance to silverleaf whitefly. Entries with okra leaf trait had lower whitefly infestations than entries with normally shaped leaves. High leaf trichome density, as in the hirsute variety Stoneville 474, was associated with high whitefly infestations. Finally, in contrast to results in a previous year, there was no correlation between whitefly density and the distance between the abaxial leaf surface and minor vascular bundles. The lack of a correlation between whitefly density and vascular bundle depth may be explained by a new morphological study showing that whitefly stylets are much longer than previously thought. Thus, vascular bundle depth would not be expected to be a limiting factor in the ability of silverleaf whitefly to colonize different cotton varieties.

There were two additional studies on the relationship between trichome density and silverleaf whitefly infestation in cotton, and each compared two varieties, a hirsute variety (Stoneville 474), and a glabrous variety (NuCOTN 33B or DPL 5415). Similar to the studies summarized above, the hirsute variety in these two studies had a much higher whitefly infestation than the glabrous variety in two Arizona field trials. However, while trichome density appears to be strongly associated with relative whitefly resistance among varieties, there is not a simple relationship between trichome density and whitefly abundance *within* varieties. Within each variety, leaf trichome density declined steadily with the leaf's position along the stem: trichome density decreased from top (younger) leaves to low (older) leaves. However, the abundance of silverleaf whitefly nymphs among the different leaf positions followed a different pattern and peaked on leaf numbers 3-5 (from the top) which had intermediate trichome densities relative to other leaf positions within the same variety. Other morphological differences among leaf age also were described: compared to old leaves, young leaves were smaller, had smaller leaf areole areas, had a higher vascular bundle density, had a greater number of terminal vein endings per unit area, had a greater number of lysigenous glands per unit area, and had minor vascular bundles closer to the abaxial leaf surface. However, the roles of these leaf morphological characteristics in leaf age preference or suitability were not examined.

Using the electrical penetration graph (EPG) technique, stylet penetration behavior of silverleaf whitefly adults was compared between two near-isolines of tomato:

Motelle, a variety with the *Mi* gene, and its near isoline, Moneymaker, that lacks the *Mi* gene. The *Mi* gene provides nematode and aphid-resistance in tomato. Previous work demonstrated that Motelle is significantly less suitable as a host plant for silverleaf whitefly than Moneymaker; thus implicating the *Mi* gene in partial resistance against silverleaf whitefly in addition to resistance against nematodes and aphids. Stylet penetration behavior strongly suggests that the partial resistance against whiteflies in the variety Motelle is due to factors in the epidermis and/or mesophyll that inhibit the whiteflies from reaching phloem sieve elements. In contrast, once the stylets reach a sieve element, whitefly behavior did not differ between the two varieties. Thus, phloem sap of the two varieties appears to be equally acceptable to the whiteflies.

Physiological Interactions Between Whiteflies and Plants.
A high silverleaf whitefly infestation of cotton leaves was shown to reduce photosynthesis and transpiration and increase leaf surface temperatures in greenhouse tests. Field infestations decreased lint yield in cotton.

On collards, silverleaf whitefly populations increased until plant maturation, and then declined as plant quality declined late in the season (early to mid June in this Texas study).

Two colonies of silverleaf whitefly, one reared on alfalfa, and the other reared on cotton, were confined to alfalfa plants to measure fecundity. Whiteflies from the alfalfa-reared colony were consistently more fecund than whiteflies from the cotton-reared colony, suggesting that conditioning to a plant species can enhance fecundity on that plant species.

The pedicel of whitefly eggs is physiologically capable of taking up water and solutes from the host plant. This is apparently necessary for egg survival.

Plant Molecular Response to Whitefly Feeding.
Nymphal feeding by silverleaf whitefly (*Bemisia argentifolii*) and by sweetpotato whitefly (*B. tabaci*) differentially induced two genes, *SLW1* and *SLW3* in squash. *SLW1* is a MB20 peptidase-like gene that also can be induced by methyl jasmonate, ethylene, and ABA treatments; whereas *SLW3* is a □-glucosidase-like gene that is not induced by these factors. *SLW1* RNAs were detected in infested leaves and leaves distal to the infested leaves by *B. argentifolii*, but not by *B. tabaci*. *SLW1* tRNAs accumulate in flowers and fruit of non-infested and infested plants. *B. argentifolii* caused increases in *SLW3* RNA levels in infested leaves and in leaves distal to the infested leaves; whereas, *B. tabaci* induced *SLW3* RNAs only in infested leaves and in leaves adjacent to the infested leaves. *SLW3* RNAs were only in leaves and not in other plant organs.

In tomatoes, feeding by silverleaf whitefly (*Bemisia argentifolii*) and by greenhouse whitefly (*Trialeurodes vaporariorum*) induced pathogenesis-related (*PR*) genes, but not genes regulated by the wound-induced octadecanoid pathway. Basic *PR* gene RNAs, such as basic ß-1,3-glucanase and basic chitinase, accumulated to high levels; whereas acidic *PR* gene RNAs were present at low levels. This indicates that the salicylic acid-independent pathway is strongly activated, while the SA-dependent pathway is weakly induced. In support of this, salicylic acid concentrations did not increase significantly following whitefly feeding. These studies indicate that tomato plants perceive phloem-feeding silverleaf and greenhouse whiteflies in a manner distinct from that of chewing insects whose *PR* gene responses have also been examined.

Two lab trials were conducted sequentially to evaluate SLWF preference for two different cucurbit hosts (watermelon and cantaloupe) treated with eight different plant growth-promoting rhizobacteria (PGPR) and the subsequent effect on Pathogenesis-Related (PR) protein induction. SLWF preferred to oviposit on PGPR treated watermelon and cantaloupe compared to the untreated control by at least two to one depending on treatment. SLWF nymph counts followed the same trend, but were more variable. Adult whiteflies preferred PGPR treated plants 4- and 8-fold more to the untreated for watermelon and cantaloupe, respectively. However, there was a positive correlation between leaf area and SLWF numbers detected for cantaloupe indicating preference may be due to leaf size as a result of the PGPR treatment. PR proteins analyzed included chitinase, glucanase and peroxidase. No significant treatment interactions could be detected among the PGPR treatments. Only the date interaction was significant indicating that SLWF infestation was more effective in inducing PR proteins than PGPR treatments when proteins were induced. However, sharp contrasts were found between these two cucurbits in terms of levels and times of PR protein induction.

Whitefly Feeding Behavior.
Silverleaf whitefly adults and nymphs initiate probes over secondary and tertiary veins, as well as between veins of cotton leaves. The greatest number of penetration sites are directly through epidermal cells rather than through the common wall between epidermal cells or through stomatal pores. While the entry of stylets into the plant appears to be mostly through the common wall between adjacent epidermal cells when examined by light microscopy, the greater resolution of electron microscopy indicates that most of these penetrations actually go directly into the epidermal cells. The depth of stylet penetration can be over 300 microns.

In a study on the effect of plant nitrogen availability to silverleaf whiteflies, whiteflies were fed on nitrogen-stressed muskmelon plants. The concentration of amino acids in the honeydew was markedly reduced when

whiteflies fed on nitrogen-stressed plants. This indicates that honeydew composition is very sensitive index of nitrogen availability to whiteflies. Interestingly, the amino acid composition in the whitefly bodies was not affected by short term (2-4 days) feeding on nitrogen-stressed plants.

Effect of Natural Plant Products Against Whiteflies. The plant product, azadiractin, was effective to moderately effective against silverleaf whitefly in three years of field trials in Arizona cotton. Although azadiractin was applied as conventional insecticides (i.e., sprayed), its origin as a product of plant genes opens the possibility of inserting genes for these insecticidal compounds into crop plants as future advances in molecular biology allow.

Table E. Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

Research approaches	Year 1 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Characterize resistance mechanisms and identify chemical/morphological components, and study effects of insect adaptation.	Identify potential sources of germplasm for disease, plant disorders and whitefly resistance.[a]	X		Research was conducted on identifying potential sources of germplasm for whitefly resistance in alfalfa, cotton, melon, cole crops, and cucurbits; and resistance to virus symptoms and silverleaf disorder in cotton and cucurbits, respectively. These studies included research on plant tolerance, antibiosis, and antixenosis. Antixenosis was found not to be responsible for resistance to squash silverleaf in two zucchini lines.
Develop molecular level techniques to produce resistant germplasm.	Identify physiological processes of whiteflies to target for inhibition.	X		Characterization of plant genomone was demonstrated in tomato and squash. Pathogenesis related mRNAs accumulated in response to whitefly feeding on tomato leaves. Data on whitefly probing behavior indicates that host evaluation phase of *Bemisia*-host interaction is dominated by probing.
Incorporate resistance traits into commercial genotypes.	Identify and isolate genetic sources of resistance for transformation and/or breeding.	X		From promising genetic materials, inbreeds, F_1 and F_2 progenies, and assorted cultivars were studies for whitefly resistance (in alfalfa, cotton, melon and squash), and susceptibility to diseases (in cotton) and plant disorders (in squash). Including plant geneticists and other specialists on the research team has been an asset.
Determine influence of host plant morphology, physiology and phenology on feeding behavior and competition.[b]	Characterize nutritional and other preference properties of various host plants.	X		Research was studied on the acceptability of cotton and vegetable hosts on whitefly feeding behavior. Work was conducted on distance from abaxial surface to minor veins, and feeding response on abaxial and adaxial surfaces of different hosts.
Define whitefly feeding and oviposition behavior and investigate approaches for interrupting whitefly feeding and digestion.[c]	Investigate approaches for interruption of feeding, assimilation, development and reproduction.	X		The host evaluation phase of *Bemisia*-host interactions was shown to dominate by probing, and the time spent in a particular behavior was affected by imidacloprid when the whitefly came into contact with the chemical in its diet rather than on the leaf surface. Intercropping of resistant within susceptible cole crops did not lessen the abundance of whiteflies.

Table E. Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions. (Continued)

Research approaches	Year 1 Goals Statement	Progress Achieved Yes	No	Significance
Study whitefly toxicogenic plant reactions.	Determine effects of whitefly feeding on host plant physiology, morphology and anatomy.	X		Research on tomato identified a gene that is specifically induced by whitefly feeding. Four classes of genes were identified in inducing squash leaf silvering. These genes were further characterized by hybridization, sequence analysis and complementation studies.

[a] See Table B for additional plant disease resistance research.
[b] See Section A.
[c] See Section A, approach #9.

Table E. Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

Research approaches	Year 2 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Characterize resistance mechanisms and identify chemical/morphological components, and study effects of insect adaptation.	Determine physiological and/or morphological basis for resistance, & effects of host-plant history and insect adaptation on plant resistance to whiteflies. Continue to identify resistant germplasm.	X		Selection for a whitefly resistant variety of alfalfa is close to completion; release of a commercial variety is expected within a few years. Whitefly-resistant or partially whitefly-resistant varieties of a number of crops have been identified, including cotton, collard, and melons. Varieties of cotton and tomato with resistance or partial resistance to whitefly-transmitted viruses also have been identified. In collards, the glossy leaf trait, and in cotton, the okra-leaf trait and large leaf surface to vascular bundle depth have been implicated as mechanisms of whitefly resistance in plants. Increased levels of phenolics and peroxidase in response to plant stress have been associated with decreased whitefly performance in tomato. In *Datura wrightii*, glandular trichomes were demonstrated to be a very effective mechanism of resistance to whiteflies.
Develop molecular level techniques to produce resistant germplasm.	Identify natural products for inhibiting processes.	X		The natural plant products, neem seed extract, azadiractin, and extract of bitterwood, were shown to be effective insecticides against silverleaf whitefly.
Incorporate resistance traits into commercial genotypes.	Insert genes into plants[b] via plant transformation.	X		Resistant commercial lines of alfalfa are close to release and commercial varieties of collard have been shown to exhibit whitefly resistance. Also, lines of cotton and melon have been identified with partial whitefly resistance. No progress has been made in the specific year 2 goal of inserting whitefly resistance genes into plants via transformation.

Table E. Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

Research approaches	Year 2 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Determine influence of host plant morphology, physiology and phenology on feeding behavior and competition.[b]	Determine the biochemical mechanism regulating adaptation to host plants.	X		Morphological plant traits such as okra-leaf and large distance from leaf surface to vascular bundles in cotton, and glandular trichomes in *Datura wrightii* have been shown to provide partial or complete whitefly resistance. Fluctuations in amino acid concentrations over the lifespan of melon leaves were correlated with whitefly performance. Also in melons, group feeding by whiteflies was shown to create a nutrient sink in the plant, and thus provide the whiteflies with improved amino acid nutrition. Senescence in poinsettia reduces host plant quality for silverleaf whitefly. In cotton, decreased nitrogen fertilization decreases whitefly populations. In tomato, plant stress caused by fertilizer and/or water deficiency reduces host plant quality for silverleaf whitefly.
Define whitefly feeding and oviposition behavior and investigate approaches for interrupting whitefly feeding and digestion.[c]	Identify physiological and morphological mechanisms regulating processes.	X		Improvements have been made in a system for rearing whiteflies on an artificial liquid medium. This will allow direct experimentation on the role of specific plant nutrients and allelochemicals on whitefly feeding and performance. Stylet contact with minor vascular bundles is essential for successful whitefly feeding on cotton. The fine structure of whitefly eggs and their attachment to host leaves has been studied with electron microscopy, and the distal end of the egg petiole that is inserted into the host leaves possesses morphological structures that suggest a role in water uptake from the host leaf which is a very important process for egg survival.
Study whitefly toxicogenic plant reactions.	Determine biochemical basis for physiological response of plant.	X		Genes specifically induced by whitefly feeding have been identified in tomato and in squash. These genes may play a role in the plant's defensive response to the whitefly and/or the plant's toxicogenic reaction such as irregular ripening in tomato and silverleaf symptom in squash.

[a] See Table B for additional plant disease resistance research.
[b] See Section A.
[c] See Section A, approach #9.

Table E. Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

Research approaches	Year 3 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Characterize resistance mechanisms and identify chemical/morphological components, and study effects of insect adaptation.	Elucidate biochemical and molecular basis for resistance. Continue to identify resistant germplasm.	X		Selection for a whitefly resistant variety of alfalfa is close to completion; release of a commercial variety is expected within a year. Whitefly fecundity tests on clonal propagules of alfalfa plants chosen in the field for whitefly resistance indicate that the field-selection criteria reflect actual resistance. Fecundity of whiteflies on alfalfa was higher for alfalfa-reared whiteflies than for cotton-reared whiteflies. This suggests whitefly adaptation to a crop species. In cotton, the okra-leaf trait and glabrous-leaf trait have been again demonstrated as a mechanisms of partial resistance against whiteflies; however, closer scrutiny of an earlier report that a large leaf surface to vascular bundle depth confers whitefly resistance has been discredited. This is useful information so that resources can be focused on examining effective mechanisms of resistance and avoid wasting resources on unlikely mechanisms. The mechanism of resistance against whiteflies in a tomato variety carrying the *Mi* gene has been shown to be due to factors encountered by whiteflies before they penetrate sieve elements rather than factors in the phloem sap. Varieties of cotton, cantaloupe, and poinsettia with resistance or partial resistance to whiteflies have been identified; and varieties of cotton and tomato with resistance or partial resistance to whitefly-transmitted viruses have been identified. Comparison of whitefly behavior on different plant species that range in suitability from good host to poor host detected little difference in whitefly behavior during initial contact with the plant. Whiteflies oviposited even on poor hosts, indicating non-selectivity on the part of the ovipositing female. This suggests that whiteflies will readily oviposit on resistant crops, and consequently mechanisms of plant resistance will be continuously challenged by migrating whiteflies.

Table E. Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

Research approaches	Year 3 Goals Statement	Progress Achieved Yes	No	Significance
Develop molecular level techniques to produce resistant germplasm.	Isolate the relevant biosynthetic enzymes that encode for natural products inhibiting processes.	X		The natural plant products, azadiractin, was shown to be an effective insecticide against silverleaf whitefly. Presently, there are no attempts to insert the genes for this plant product into crop plants.
Incorporate resistance traits into commercial genotypes.	Evaluate potential of newly transformed germplasm.	X		Whitefly-resistant commercial lines of alfalfa are close to release. Commercially available varieties of cotton, cantaloupe, and poinsettia that are resistant or partially resistant against whiteflies or whitefly-transmitted viruses have been identified. No genetically transformed germplasm has yet been evaluated for whitefly resistance.
Determine influence of host plant morphology, physiology and phenology on feeding behavior and competition.[b]	Determine changes in whitefly gene expression in response to host manipulation.	X		In cotton, the okra-leaf trait and glabrous-leaf trait have been confirmed as a mechanisms of partial resistance against whiteflies; however, closer scrutiny of an earlier report that a large leaf surface to vascular bundle depth confers whitefly resistance has been discredited. Factors encountered by whiteflies during their stylet penetration to vascular bundles has been shown to confer partial resistance in a tomato variety with the *Mi* gene. Phloem sap factors do not appear to play a role in this resistance. The known host plant range of silverleaf whitefly has been expanded to include some medicinal plants and weed species. An abundance of host plant species suitable for overwintering in California's San Joaquin Valley have been identified; thus a strategy of host-free periods for whitefly management is not very promising in the San Joaquin Valley.

Table E. Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

Research approaches	Year 3 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Define whitefly feeding and oviposition behavior and investigate approaches for interrupting whitefly feeding and digestion.[c]	Determine biochemical and molecular basis for inhibiting processes.	X		Morphological studies on whitefly stylets indicate that they are sufficiently long to reach minor vascular bundles (the major feeding site) from virtually any place on the abaxial leaf surface of cotton. This makes variation in vascular bundle depth an unlikely mechanism of resistance to whiteflies in cotton. Variation in nitrogen fertilization has been shown to decrease amino acid concentrations in phloem sap and thus affects nutrition available to whiteflies. Whitefly feeding differentially induces pathogenesis-related (PR) proteins in two cucurbit species, cantaloupe and watermelon, and apparently is not affected by treatment with plant growth-promoting rhizobacteria (PGPR).
Study whitefly toxicogenic plant reactions.	Elucidate changes in plant gene expression.	X		Two genes, one of which appears to be a general plant defense, have been shown to be differentially induced in squash by silverleaf and sweetpotato whiteflies. This may be related to the different toxicogenic effects of these two whitefly species on squash. The activation of these genes is systemic. In tomatoes, feeding by both silverleaf whitefly and greenhouse whitefly induced pathogenesis related genes, but not genes regulated by the octadecanoid pathway. These studies indicate that tomato plants perceive phloem-feeding silverleaf and greenhouse whiteflies in a manner distinct from that of chewing insects.

[a] See Table B for additional plant disease resistance research.
[b] See Section A.
[c] See Section A, approach #9.

Reports of Research Progress

Section F: Integrated and Areawide Pest Management Approaches, and Crop Management Systems
Co-Chairs: Steve Castle and William Roltsch

Investigator's Name(s): D. H. Akey and T. J. Henneberry.

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Research & Implementation Area: Section F: Integrated and Area-wide Pest Management Approaches, and Crop Management Systems.

Dates Covered by the Report: June 1997-September 1999

Progress in Development of IPM for Upland Cotton in Arizona Using Biorational and Biopesticide Agents for Control of Silverleaf Whitefly (SLWF) *Bemisia argentifolii* and Other Cotton Pests

An Integrated Pest Management (IPM) program of biorational/biopesticide agents was tested for impact on beneficial arthropods. Biorational agents replaced conventional chemistries and considered Insecticide Resistance Management (IRM). Deltapine cotton was planted and furrow irrigated: 1997- DP 5415; 1998-9- NuCOTN 33^B. Plots were 0.10ac; separated by fallow rows and alleys. Spray applications were by ground boom: 1 center nozzle/row, and inter-row drops with 2 or 4 swivel nozzles angled upward, applied at 80 or 250 psi and 30 gal/ac. Sweeps were taken weekly (25/ each plot) for *Lygus,* predators, parasites, and thrips. Entomopathogenic fungi used against silverleaf whitefly included: *Beauveria bassiana*, as Naturalis®L (Troy Biosciences) 10 oz product/ac, 2.3x 10^7 conidia/ml, as Mycotrol® (Mycotech)[WP in 1997 0.5 lbs/ac, 2 x 10^{13} spores/lb, ES in 1998 and 9 0.5 pt/ac, 2 x 10^{13} spores/qt], and *Paecilomyces fumosoroseus* as PFR- 97™ (Thermo Trilogy), 0.025 lbs / gal, 1x 10^9 CFU/gm equivalent 20% product. Insect growth regulators included: azadirachtin as Bollwhip™ (Thermo Trilogy), 4.5% form., at 3, 6, and 9 oz in 1997 and 6 oz/ac in 1998-9, product/ac, buprofezin as Applaud™ 70WP (AgrEvo) 0.35lb. AI/ac; and pyriproxyfen as Knack™ 0.86 EC (Valent USA) 0.054 lb AI/ac. As SLWF populations met action thresholds (Univ. AZ Ext.) applications were made. Biorationals for other insects included: pink bollworm sex pheromone, alone or baited ($^{1/10}$rate chlorpyrifos); BT gene-NuCOTN 33^B; diflubenzuron -Dimilin®; BT sprays- e.g. DiPel®; and K-salt of fatty acid- M-Pede™ (all per label). Other insects included: pink bollworm, beet armyworm, cabbage looper, and saltmarsh caterpillar. Treatments were random block in design and included a "Best Agricultural Practice" (BAP) and an embedded control; plus, a single1-ac block control. Numbers of treatments (t) and spray applications (sa), respectively, were: 1997,16 t, 12 sa; 1998, 13t, 9sa;1999, 10t, 8sa. Efficacies are given as % reduction from block control. In 1997, Bollwhip™ was effective at controlling SLWF at all three rates. PFR-97 efficacies were: 83% for eggs; 78 and 75% for small and large nymphs, respectively. BAP (Applaud™ and Knack™) efficacies were similar. Naturalis®L and Mycotrol® gave excellent control of SLWF(>PFR-97*)*. 1998 had unfavorable weather for cotton production. SLWF reached action thresholds late July. In an 8-day period, 2 sprays were applied, then populations dropped sharply and did not rebound. Bollwhip™ efficacies were: eggs, 37 %; small nymph, 32 %; and large nymphs, 66 %, respectively. Efficacies were: eggs; 41 and 23 % as Naturalis® L and Mycotrol® ES, respectively; and PFR-97™, 30%; small nymphs; 6 and 19 % as Naturalis®L and Mycotrol® ES, respectively; and PFR-97™; 24%; large nymphs, 28 and 8 % as Naturalis® L and Mycotrol® ES, respectively; and PFR-97™, 4 %. Applaud™, the only BAP treatment applied, had egg, small nymph, and large nymph efficacies of 28, 37, 38 %, respectively. Though low, these efficacies held SLWF populations below action thresholds. In 1999, Bollwhip™ efficacies were: eggs, 37 %; small nymph, 32 %; and large nymphs, 66 %, respectively. Mean number of large nymphs in Bollwhip™ plots did not exceed treatment threshold. BAP, Buprofezin then pyriproxyfen 2wks later, provided season control with egg, small nymph, and large nymph efficacies of 42, 75, and 95 %, respectively. Efficacies of Mycotrol® ES and Naturalis® L respectively, were as follows: 26 and 41% against eggs; 23 and 46% against small nymphs; and 56 and 74% against large nymphs. Efficacies of PFR -97™ were: 50% against eggs; 49% against small nymphs; and 78% against large nymphs. Attempts to control all pests, with biorational agents, replacing conventional chemistries, failed because of strong *Lygus* pressure: in 1997, 1 application of oxamyl, Vydate®; 1998 several required but only 1 applied; and 1999, entire season-above threshold but no conventional applications made. Presently, we have no biorational agents for *Lygus*.

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Research & Implementation Area: Section F: Integrated and Areawide Pest Management Approaches, and Crop Management Systems.

Dates Covered by the Report: 1996 - 1999

The CGIAR Systemwide IPM Project on Sustainable Integrated Management of Whiteflies as Pests and Vectors of Plant Viruses in the Tropics

In 1995, the Systemwide Program on Integrated Pest Management (SP-IPM) was established by the Consultative Group on International Agricultural Research (CGIAR) in recognition of the importance of IPM to sustainable development. One of the objectives of the SP-IPM is to promote collaboration between CGIAR centers, national agricultural programs (NARS), and basic research institutions, on topics of mutual concern and endeavor. To date, the steering committee has approved 12 areas of collaboration, including whiteflies as pests and vectors in the Tropics. In 1996, the Center for International Tropical Agriculture (CIAT) in Cali, Colombia was designated as the convening center to formulate a systemwide proposal on the Sustainable Integrated Management of Whiteflies as Pests and Vectors of Plant Viruses in the Tropics.

To that end, a Task Force meeting for the CGIAR Whitefly IPM Project was held at CIAT from February 13-15, 1996. The Task Force meeting included 24 participants representing the CGIAR centers, national and regional agricultural programs, and basic research institutions. The Task Force agreed on three priority problems to be addressed by the Project: 1) whiteflies as pests in Tropical highlands; 2) whiteflies as vectors of plant viruses in mixed cropping systems in the low-to-mid-altitude Tropics; and 3) whiteflies as pests and vectors of plant viruses in cassava.

The Whitefly IPM Project initiated in 1997 with Phase 1, start-up, funding from the Danish International Development Agency (Danida). The objective of Phase 1 was to: 1) form a pan-tropical network for professionals working on whiteflies and whitefly-transmitted viruses in the Tropics; and 2) improve the characterization of the prioritized whitefly problems in the Tropics, in order to lay the foundation for a sound research agenda as well as select critical geographical areas (hot spots) to target intensive research activities and IPM component testing for Phase 2 work.

Since 1997, the Project has continued to expand. The formal partners in the network now include:
International Agricultural Research Centers (CIAT, ICIPE, IITA, AVRDC, CIP)
Advanced Research Organizations (in Australia, Germany, New Zealand, UK, and the US)
NARS institutions in 30 countries across the Tropics (12 in Latin America, 10 in Africa, 8 in Asia).

In addition to Danida, the Donor Partners now include: the Australian Center for International Agricultural Research (ACIAR), the Department for International Development (DFID) of the UK, the FAO-Global IPM Facility (GIPMF), the New Zealand Ministry of Foreign Affairs and Trade (MFAT), the United States Agency for International Development (USAID) and the Agricultural Research Service of the United States Department of Agriculture (USDA--ARS).

In August of 1999, the USDA--ARS, signed a Scientific Cooperative Agreement with CIAT. The research objectives of the SCA, to be carried out in collaboration with the USDA--ARS, laboratory in Fort Pierce, Florida, will focus on the epidemiology of whitefly-transmitted geminiviruses. The service objectives of the SCA are to link the US Whitefly Research and Action Plan with the CGIAR Whitefly IPM Project. The objective of this talk is to present a tentative proposal for initiation of those linkages and to stimulate discussion on that proposal.

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Research & Implementation Area: Section F: Integrated and Areawide Pest Management Approaches, and Crop Management Systems

Dates Covered by the Report: Summer 1999

Reduced Whitefly Infestations in Cotton Using a Melon Trap Crop

Trap cropping involves the manipulation of crop stands in time and space with the objective of concentrating a pest species within the trap crop rather than the main crop. This can be achieved by using a trap crop that is the same species or cultivar as the main crop, but which is grown asynchronously to the main crop in order to concentrate either early or late pest invaders. Alternatively, a trap crop that is contemporaneously grown with the main crop will probably involve a different plant species that is more attractive to the target pest than the main crop. Assuming that either approach is effective at concentrating the target pest, then the real challenge begins with managing the pest in the trap crop effectively to prevent the trap crop from becoming a source of the pest rather than a sink.

Whiteflies are amenable to trap crop management for a number of reasons. Foremost is that whiteflies are highly polyphagous, utilizing many different crop, ornamental and wild hosts, but also are differentially attracted to their various plant hosts. Basic differences among plant species in food quality and as reproductive hosts probably determine why certain plant species accumulate and generate more whiteflies than other species. Whatever the mechanism(s), years of observation and data collection in the field have amply demonstrated that much higher numbers of whiteflies are found on melon plants than on other crop plants. In addition to putative superior host characteristics for silverleaf whiteflies, the use of melons as a trap crop is advantageous in that cultivation and pest management practices are well determined. Thus, there is greater certainty to manipulating an agronomically-proven trap crop for the intention of minimizing the impact of whiteflies on the cotton main crop than would be true for a typically non-crop trap host.

A second year of field experiments was completed in 1999 at the Maricopa Ag Center in Arizona to explore the potential of using a melon trap crop to reduce whitefly infestations in cotton. The experimental design was altered from 1998 to gain isolation among treatment blocks by using 4 separate fields that helped to avoid the influence of one treatment upon the other. A consistent response of significantly fewer whiteflies in cotton planted within a surrounding melon trap crop, relative to the same area of cotton without the trap crop, was observed throughout the July-September sampling period. Better chemical management of whiteflies in the melons during the second season helped to reduce the large differential in whitefly densities between melons and cotton observed the previous year, but preferentially contributed to a greater differential observed between melon-protected cotton and unprotected cotton. Although the infestation buildup was delayed and the season-long densities of whiteflies in the melon-protected cotton were reduced, the action thresholds for treatment with IGRs were ultimately attained and exceeded. In the present management environment of perhaps only 1 IGR treatment per season, it is unlikely that the melon trap crop approach would provide acceptable control unless a grower was willing to tolerate late-season whitefly densities higher than the current IPM recommendations.

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Research & Implementation Area: Section F: Integrated and Areawide Pest Management Approaches, and Crop Management Systems.

Dates Covered by the Report: 1999

Preliminary Data of the Effects of Cotton Defoliant Chemicals on *Bemisia Argentifolii* Mortality and its Parasitoid Survival

Lethal and sublethal effects of two commonly used defoliants, Def and Dropp, on whitefly, *Bemisia argentifolii*, and its parasitoids, *Eretmocerus eremicus* and *Eretmocerus hyati*, were evaluated in laboratory and greenhouse tests. Whitefly eggs and adults were more susceptible to defoliant treatments than larvae. The reduction in feeding sites differentially affected whitefly nymph mortality depending on instar. Sublethal effects of Def, Dropp or their mixture on whitefly were manifested through reduction of percentage female progeny and the number of eggs deposited per female per day after spraying young nymphs. The timing of application significantly affected parasitoid survival. After defoliant treatments of whitefly nymphs parasitized with early instar *E. eremicus* larvae, the number of parasitoid female progeny was significantly reduced and their longevity was significantly shorter than those of controls.

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Research & Implementation Area: Section F: Integrated and Areawide Pest Management Approaches, and Crop Management Systems.

Dates Covered by the Report: August 1997-August 1999

Living ground covers are effective for managing whitefly-vectored geminiviruses in tomatoes

The Tomato Yellow Mottle Virus (ToYMoV), so far reported only for Costa Rica, is one of some 17 geminiviruses affecting tomatoes in the Americas, and is vectored by *Bemisia tabaci*. The impact of diseases caused by these viruses on crop yield depends on plant age at time of infection, and is greatest during the first eight weeks after germination (critical period). In the search for management approaches to deal with both whiteflies and geminiviruses, a preventative scheme suited for resource-poor growers who normally plant staked tomatoes on small plots (< 0.5 ha), has been proposed. This scheme focuses on minimizing contact between the vector and the tomato plant during the critical period, and includes protection of seedbeds with tunnels of fine netting, as well as the use of living mulches after transplanting, which appear to mask or conceal the crop from immigrating viruliferous whiteflies.

The role of living ground covers in masking tomatoes from whiteflies in Costa Rica was appraised in large plots (2400 m^2) over two years, to minimize interference between treatments. A randomized complete block design was used, with four replicates, each occupying an entire location over one season. Treatments consisted of six types of ground covers: *Arachis pintoi* (perennial peanuts) (Leguminosae), the low-growing weed "cinquillo" (*Drymaria cordata*, Caryophyllaceae), coriander (*Coriandrum sativum*, Umbelliferae), silver plastic, bare ground treated with imidacloprid (commercial standard), and bare ground untreated (absolute control). Living covers were established well before tomatoes were transplanted. Silver plastic (silver/black, coextruded, 56" x 1.25 Mls; Olefinas S.A., Guatemala) was put in place over the 30 cm-wide bed two weeks before transplanting. Imidacloprid (Confidor 70 WG; Bayer) was applied to the foliage at the recommended rate (9 g/ 40 m^2 of seedbed surface) a week before transplanting, and two drench applications (250 g/ha) two and four weeks later. No other insecticides were used in any plot during the rest of the season.

Silver plastic was the best treatment in terms of reduction of incoming whitefly adults, delay of ToYMoV dissemination, reduction of disease severity, yield (36 t/ha) and net profit (US$ 30,347/ha). Normal yields in Costa Rica range from 21-35 t/ha. Silver mulch was followed by living covers (with yields ranging from 17-22 t/ha, and net profits from $ 8-16,000/ha) and bare ground with imidacloprid (15 t/ha, $ 5,700/ha). Yield from control plants was as low as 5 t/ha and losses amounted to $ 2,500/ha. Among living covers, on the average, perennial peanuts provided both the highest yield and net profit (22 t/ha and $ 16,000/ha), followed by coriander (19 t/ha, $ 10,000/ha) and Drymaria (17 t/ha, $ 8,000/ha). However, yields in one of the replicates were as high as 25 t/ha (coriander), 36 t/ha (Drymaria) and 40 t/ha (perennial peanuts). Furthermore, since coriander provides additional economic returns when sold ($ 5,000/ha, on the average), and is much easier to establish and remove than the other living covers, it is being recommended for commercial use. Nevertheless, control by either silver plastic or living covers broke down under extremely high inoculum pressure in one replicate. Thus, individually applied preventative and curative management may have to be supplemented with area-wide preventative approaches, such as planting dates and crop-free periods, to successfully manage the geminivirus-whitefly complex in Costa Rica.

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Research & Implementation Area: Section F: Integrated Pest Management Approaches, and Crop Management Systems.

Dates Covered by the Report: July 1997 - July 1999

Compatibility of Selected Insect Growth Regulating Insecticides with the Whitefly Parasitoid *Eretmocerus Eremicus* for Control of *Bemisia Argentifolii* on Poinsettias

Five insect growth regulators (IGR's), Applaud (buprofezin), Knack (pyriproxyfen), Precision (fenoxycarb), Fulfill (pymetrozine), Enstar II (S-Kinoprene) were examined in the laboratory and greenhouse for compatibility with the silverleaf whitefly (*Bemisia argentifolii*) parasitoid *Eretmocerus eremicus*. Specifically, we quantified adult *E. eremicus* mortality foraging on poinsettia leaves without whitefly nymphs when exposed to residues of 6, 24, and 96 hours of age. Parasitoid mortality resulting from host feeding by female wasps on *B. argentifolii* nymphs treated with IGR's 24 and 96 hours of age were determined also. The effect of IGR's on developing *E. eremicus* larvae was determined by treating parasitized whitefly nymphs 5 and 14 days after they had been parasitized by *E. eremicus*. The repellancy of aged IGR residues to foraging female *E. eremicus* was quantified by visually observing wasps that had the choice of foraging on either a treated or untreated section of poinsettia leaf. All experiments used water as a control treatment. Greenhouse level experiments were conducted to determine the efficacy and economics of low parasitoid release rates (one female *E. eremicus* released per plant per week of the growing season) with selected IGRs for *B. argentifolii* control on commercially grown poinsettias. Efficacy of combining IGRs and *E. eremicus* was determined by comparing whitefly control to greenhouses in which parasitoid releases alone were made and greenhouses in which growers used systemic insecticides for whitefly control.

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Research & Implementation Area: Section F: Integrated and Areawide Pest Management Approaches, and Crop Management Systems

Dates Covered by the Report: 1999

Population Dynamics of Silverleaf Whitefly on Spring Collard and Relationship to Yield in the Lower Rio Grande Valley of Texas

Seasonal population dynamics of the silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring [formerly known as the sweetpotato whitefly, *B. tabaci* (Gennadius) Biotype "B"], was investigated on collard (*Brassica oleracea* L. variety *acephala*) during spring 1998 and 1999 in the Lower Rio Grande Valley of Texas. Yield loss caused by whitefly was determined by using insecticides to suppress whitefly populations to a low level. Although *B. argentifolii* populations of adults and immatures fluctuated greatly from April to June during the two seasons, the relative values were similar. Adult whiteflies first appeared on the plants in early April, increased rapidly within the month, peaked in May, and then declined at the end of the season in early or mid-June. Whitefly eggs appeared on plants soon after adults were found, but high numbers of eggs were observed on foliage until late May 1998 and mid- and late May 1999. Nymphs and pupae increased slowly before June 1998 and increased early in May 1999. Whitefly population levels appeared to be positively associated with the availability and the growth of host plants until plant maturation, afterwards being negatively related with plant quality in the late season. Temperature, rainfall, and natural enemies were not key factors in regulating population dynamics during the two seasons. Collard plants with heavy infestations of whiteflies were unmarketable because of the damage caused by honeydew and sooty mold on the foliage. Application of a combination of fenpropathrin (Danitol) and acephate (Orthene) not only significantly reduced the whitefly infestation levels but also reduced plant foliar damage, resulting in marketable foliage with 6- to 7- fold greater yield and higher quality compared with the untreated plants.

Research Summary

Integrated and Areawide Pest Management Approaches and Crop Management Systems

Compiled by Steve Castle & Bill Roltsch

The combining of multiple control tactics into a balanced and coordinated pest management program is a principle goal of integrated pest management (IPM). Ideally, IPM is a knowledge-driven pursuit that incorporates research findings and practical experience into a refined program of pest control. A series of decision-making tools are developed and implemented, then evaluated in terms of their effectiveness and costs. Too often, however, the basic groundwork is not laid for the development of robust decision-making tools such as economic thresholds, binomial sampling plans, insecticide resistance management, etc. Without these, so-called IPM becomes a collection of ad hoc control practices that get labeled IPM only because multiple tactics are implemented, or because IPM is used synonymously (and erroneously) with pest control.

Following the development of specific control practices, their efficacy and affordability can be assessed through recording yields and input costs. Reliance upon such productivity measurements may be suitable from an economic perspective and for meeting short-term goals of agriculture, but they tell us very little about the compatibility of various control practices used in a pest management program. Architects of IPM solutions should be as interested in the pest management pathway to the bottom line as in the economic result itself. Rarely are the individual contributions of specific pest control practices elucidated, however, as very few workers have the courage to take on field projects that partition overall control into its component parts. This is customarily accomplished by studying the specific sources of mortality that impact a field population and then summarizing the results using a life table format. Inordinate dedication is required, especially for minute insects like whiteflies, to spend the hours of observation necessary to find and follow a cohort of individuals and determine the specific mortality factors that befall each one, or to document the rare few that survive to adulthood.

The keynote talks by Naranjo and Ellsworth presented findings of 4 consecutive years of observing whitefly populations in Arizona cotton fields and partitioning the different sources of mortality impacting egg and nymphal stages. A total of 14 generations were observed over this period with survivorship to adulthood ranging from a high of 27% to null. The egg and 4th instar stages were most vulnerable to mortality factors, although mortality in the crawler stage was not estimated. Predation consistently proved to be the most important source of mortality in the 4th instar but also was important in earlier nymphal stages and in the egg stage. Over all generations, egg inviability proved to be the largest source of mortality in the egg stage, but was highly variable. Most interestingly, mortality due to specific factors rarely proved to be irreplaceable. That is, a decline in mortality due to a specific mortality factor in any given generation often was met with an increase in mortality by a different mortality factor. Replaceable mortality of this sort speaks to the importance of multiple control tactics that are complementary with one another. An interesting question would be whether replaceable mortality was observed to a greater or lesser degree in various treatment plots according to the type of insecticides used, i.e. conventional or IGRs.

Development

Hilje and Stansly reported further research on the benefits of using living ground covers for protecting against the spread of geminiviruses in tomato. The concept behind this approach is that particular types of plants, when intercropped with tomato, will help mask the tomato crop from whitefly vectors that spread tomato yellow mottle virus and other geminiviruses. In addition to three different plant types used as ground covers, imidacloprid, silver plastic as a mulch cover, and bare ground were used in field experiments. The greatest reduction in numbers of incoming whitefly adults and viral disease was observed with the silver plastic followed by the living ground covers and then imidacloprid. Under conditions of high whitefly pressure, however, preventive measures represented by the silver plastic, living ground covers or imidicloprid were unable to avoid levels of colonization sufficient to avoid extensive viral disease spread. A study by Stansly (Section B) conducted in Florida demonstrated somewhat different results, relative to the efficacy of imidacloprid and silver plastic to control tomato yellow leafcurl virus (TYLCV). Under conditions of high whitefly pressure, however, the preventive measures represented by the silver plastic and living ground covers were unable to avoid heavy colonization and viral disease spread.

A second year of field studies on the use of melons as a trap crop for cotton provided evidence that whitefly infestations can be delayed and reduced when the cotton crop is surrounded by melons. Sustained control of whiteflies in the melon trap crop was possible with successive treatments of Admire®, Applaud® and Thiodan®. Work by Costa demonstrated the potential use of ultra violet-blocking films in protected environments. Orientation by whiteflies appears to be disrupted in the UV-blocked environment, thus acting to repel whiteflies and reduce colonization. Liu examined the seasonal development of whiteflies on collards in south Texas and began to establish yield relationships to whitefly densities.

Integration

There were a number of contributions this year that explored the integration of multiple tactics used to combat

whiteflies. In addition to the keynote addresses that examined the impact of applied and natural mortality factors on whitefly control in cotton fields, Hoddle et al. reported on the impact of different IGR's on the whitefly parasitoid *Eretmocerus eremicus*. Certain IGR's were more compatible with biocontrol efforts based on lower mortalities observed in *E. eremicus* populations. The impact of cotton defoliant chemistry on whitefly parasitoids and on various whitefly stages was investigated in Texas. The defoliants Def® and Dropp® both had negative affects on parasitoid and whitefly populations. Akey and Henneberry updated their work on using biorational and biopesticidal agents for whitefly control in Arizona cotton, and Pickett provided additional information on using transplants inoculated with parasitoids in Imperial Valley melon fields.

Further research on incorporating the newest members of the neonicotinoid class of insecticides into an integrated control program in spring melons was conducted in California and Texas. One disadvantage of early season use of Admire® on spring melons has been that application is optimally made at the time of planting for increased systemic uptake and residual activity, but whiteflies generally are not present in high enough densities to warrant treatment. Consequently, Admire® applications have often been made in anticipation of increasing whitefly numbers later in the crop season. Although the foliar formulation of imidacloprid has been available as Provado®, the level of control attained with Provado® has not matched that attained with Admire®. However, Liu reported that thiamethoxam (Section C), a neonicotinoid insecticide currently under development by Novartis, was as effective as Admire® when used in the spray formulation Actara® to control whiteflies in spring melons in Texas. Platinum® is also a commercial formulation of thiamethoxam, but intended for systemic uptake by plants following soil application. Platinum® appears to be slightly more versatile than Admire® in terms of responding to a pest infestation rather than anticipating one. This is because Platinum® is more mobile in soil due to higher water solubility and therefore can be applied away from the crown of melon plants, yet still move into their root zones for uptake in direct response to a whitefly infestation. Results presented by Natwick (Section C) were not as favorable in terms of the level of whitefly control afforded by Actara® relative to a systemic treatment with Admire®. It may be that higher whitefly pressure in the Imperial Valley still exceeds the capacity of spray formulations of neonicotinoids to control whiteflies as well as the control attained with systemic treatments. A further concern with the spray formulations of neonicotinoids is that beneficial insects may be more prone to toxic exposure than they are with the systemic formulations. Naranjo (Section C) reported significantly lower populations of Heteropteran predators and spiders in cotton plots treated with acetamiprid (NI-25), another foliar neonicotinoid, but with translaminar properties.

Delivery & Implementation

International participants of the 5-Year Reviews help to remind North American workers of the prominent role held by *Bemisia tabaci* as a pest of world agriculture. The serious issue of developing better management tactics for combating *B. tabaci* infestations worldwide was addressed by Anderson on the topic of the CGIAR systemwide IPM project on sustainable integrated management of whiteflies. One of the priority subject areas to be addressed by participants of this multi-continent, multi-nation project is whiteflies as vectors of plant viruses in mixed cropping systems. SLW vectored viruses have been reported as significantly affecting agricultural production in several tropical regions of the world for a number of years. This is an area that seems to gain importance each year in North America as viruses are introduced (as with TYLCV in Florida) or are newly discovered (new geminivirus infecting melons in the Imperial Valley). Our management perspective in the future may become more concerned with controlling whiteflies as vectors of viruses rather than as direct feeding pests. If this becomes the case, then information flow from collaborative projects of the sort described by Anderson may help generate more rapid solutions to newly emerging problems.

In addition to causing direct feeding damage and transmitting plant viruses, whiteflies do considerable damage to certain crops by contaminating the harvested product with honeydew. This particular problem is most severe in cotton where late season infestations of whiteflies can produce substantial quantities of honeydew that contaminate cotton lint. A new extension guide by Ellsworth et al. called "Sticky Cotton Sources and Solutions" details the impact of sticky cotton on growers and the marketplace and what steps can be taken in the field to minimize sticky cotton

Table F. Integrated and Areawide Pest Management Approaches, and Crop Management Systems.

Research Approaches[a]	Year 1 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Development:				
Study whitefly-crop interactions[b] as cultural components that affect population dynamics, e.g., water, nutrients, plant population, planting/termination/harvest dates, other farm practices, intercrop relationships.	Identify potential beneficial or exacerbating farm practices or inputs for testing.	X but limited		Only minor progress has been made on this approach (since last 5-yr review), & mainly in area-wide programs. This work is correlative, & little experimental work has been planned for or reported. Past work identified the potential or described the role of fertility status, water-stress & some other agronomic factors on *Bemisia* population dynamics. Conceptual discussion was presented on the role of pesticidal & non-pesticidal factors on *Bemisia* outbreaks.
Develop behavioral barriers[b] to whitefly colonization and population development, e.g., mulches, trap crops, inter-cropping, row covers, etc.	Review potential behavioral disrupters and evaluate as potential IPM components.	X		Progress has been made in several areas: • row covers and screens as physical barriers, • mulches and oils as behavioral barriers, • living mulches as behavioral barriers.
Integration:				
Develop Integrated Pest Management[c] systems using dual or multiple control tactics, e.g., cultural, biological, chemical, host plant resistance, etc.	Identify candidate dual or multiple control tactic systems, e.g., IGRs and natural enemy conservation.	X		Significant activity on this goal has occurred: • Insect Growth Regulators & biological control in cotton (conservation) • imidacloprid & other chemical control tactics & various forms of biological control, especially in vegetables • studies of direct & indirect effects of chemical control on bio-control agents.
Integrate sampling with other key components of IPM systems, e.g., thresholds, economics, decision-making, biological control, etc.	Develop or modify sampling systems for new crops; integrate with thresholds and decision-making.	X		Limited progress has been made in this area: • *Bemisia* distributions have been examined in tomato, • new binomial sampling system for large nymphs in cotton, & integration with thresholds for IGR decisions • sampling & IGR re-treatment decisions tested in cotton.

Table F. Integrated and Areawide Pest Management Approaches, and Crop Management Systems. (Continued)

Research Approaches[a]	Year 1 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Delivery and Implementation:				
Elevate single field/farm practices to areawide community-based contexts; develop methodology for installing and evaluating areawide control technologies and their impact.	Identify agricultural communities amenable to areawide management; conduct thorough pre-implementation evaluation.	X		Significant progress was made in this area mainly in cotton: • areas dominated by cotton were identified in AZ & CA for implementation of cooperative programs. • areas of melon and vegetable production were identified in TX for potential area-wide programs. • area-wide sampling, & decision-making was the main focus of most programs; however, coordinated natural enemy releases were also conducted.
Implement and deliver Integrated Pest Management and Integrated Crop Management systems or system components to clientele.	Develop and distribute provisional IPM & ICM recommendations.	X		Continued progress was made in this area: • IPM recommendations were distributed AZ, CA, Mexico & FL; bilateral discussions between Brazil & U.S. took place. • IPM & ICM guidelines were coordinated in AZ cotton.

[a] See Tables A to E for additional complementary research.
[b] See Tables A for additional complementary research.
[c] See Tables E for additional complementary research.

Table F. Integrated and Areawide Pest Management Approaches, and Crop Management Systems.

Research Approaches[a]	Year 2 Goals Statement	Progress Achieved Yes	No	Significance
Development:				
Study whitefly-crop interactions[b] as cultural components that affect population dynamics, e.g., water, nutrients, plant population, planting/termination/harvest dates, other farm practices, intercrop relationships.	Determine nature and character of relationship between interaction and whitefly population dynamics.	X		Nitrogen fertilization at different rates in cotton and its impact on whitefly population densities and honeydew deposition was studied. Considerable development occurred on cross-commodity integration of pesticides used in multi-cropped situations and in conceptualization of the multiple levels and factors upon which whitefly management depends.
Develop behavioral barriers[b] to whitefly colonization and population development, e.g., mulches, trap crops, inter-cropping, row covers, etc.	Conduct field-level trials; quantify impact to crop and whitefly dynamics	X		Investigations on intercropping took place in both desert and tropical environments. Although reductions in whitefly densities were observed in both systems, further experimentation is required to establish the effectiveness of the trap crops relative to more conventional management techniques.
Integration:				
Develop Integrated Pest Management[c] systems using dual or multiple control tactics, e.g., cultural, biological, chemical, host plant resistance, etc.	Initiate field testing of candidate systems.	X		A number of field studies employed multiple tactics directed against whitefly populations. Biorational insecticides were examined in combination with IGRs and other biopesticidal agents such as *Beauvaria bassiana* for control efficacy of silverleaf whitefly. There was an indication of inhibitory action by *B. bassiana* when used in combination with imidacloprid as well as deleterious effects to predators contacted by *B. bassiana* treatments. Neem products were used to reduce whitefly populations and incidence of yellow mosaic virus in India. A melon trap crop was integrated with chemical control to focus potentially disrupting treatments into a limited area while preserving natural mortality factors in cotton as the principle crop.

Table F. Integrated and Areawide Pest Management Approaches, and Crop Management Systems. (Continued)

Research Approaches[a]	Year 2 Goals Statement	Progress Achieved Yes	No	Significance
Integrate sampling with other key components of IPM systems, e.g., thresholds, economics, decision-making, biological control, etc.	Establish practical utility of system through economic analyses; field efficiencies and costs.	X		Analysis of types and patterns of chemical treatments made on a large number of cotton fields in central Arizona over a 4 year period revealed extraordinary differences in the number of treatments and amount of time that whiteflies exceeded threshold levels prior to and following the advent of the IGRs buprofezin and pyriproxyfen. The proactive initiative taken by Arizona growers to pursue chemical use harmonization across commodities required consideration of all aspects of pest and crop management. A similar whole system appraisal was made in the San Joaquin Valley with an emphasis on integrating multiple practices with diverse insecticide classes as part of an insecticide resistance management program.
Delivery and Implementation:				
Elevate single field/farm practices to areawide community-based contexts; develop methodology for installing and evaluating areawide control technologies and their impact.	Install control technologies into community; develop systems for evaluation.	X		Large areas in the San Joaquin Valley observed specific guidelines for IPM and IRM in cotton with evaluations continuing on the benefits attained over areas that did not observe these guidelines. Community wide evaluations were made on quality of whitefly management according to chemical control practices. The successful IPM and IRM programs practiced in Arizona cotton continued for a third consecutive year. Further cross-commodity develoment of these programs is under way.

Table F. Integrated and Areawide Pest Management Approaches, and Crop Management Systems. (Continued)

Research Approaches[a]	Year 2 Goals Statement	Progress Achieved Yes	No	Significance
Implement and deliver Integrated Pest Management and Integrated Crop Management systems or system components to clientele.	Conduct whole farm/operation demonstrations of IPM systems.	X		A 'best agricultural practices' demonstration project was conducted on 50.5 acres at the University of Arizona Maricopa Agricultural Center that included inputs from extension specialists in agronomy, entomology, irrigation management, weed sciences and plant pathology according to university recommendations. Whitefly management was fully integrated with management of other insect pests and required only a single application of pyriproxyfen. Lint yields of 2.81 bales/acre were higher than the historical as well as the 1998 farm-wide average. An integrated areawide management program involving the cooperation of growers, PCAs, ginners and state and university researchers was expanded during a second year in the San Joaquin Valley.

[a] See Tables A to E for additional complementary research.
[b] See Tables A for additional complementary research.
[c] See Tables E for additional complementary research.

Table F. Integrated and Areawide Pest Management Approaches, and Crop Management Systems.

Research Approaches[a]	Year 3 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Development:				
Study whitefly-crop interactions[b] as cultural components that affect population dynamics, e.g., water, nutrients, plant population, planting/termination/harvest dates, other farm practices, intercrop relationships.	Identify mechanisms governing relationship and alter or manipulate factors that suppress whitefly dynamics.	X		Progress was made with studies in Texas on seasonal dynamics of *Bemisia* on spring collards, and the impact of cotton defoliants on *Bemisia* and parasitoid populations. Work continued in California on the affect of various nitrogen levels in cotton with *Bemisia* population densities
Develop behavioral barriers[b] to whitefly colonization and population development, e.g., mulches, trap crops, inter-cropping, row covers, etc.	Apply promising technologies to high-value crop systems; field test and evaluate	X		Further progress with research on: • Living ground covers for managing whitefly-transmitted gemini viruses • Behavioral disruptance by UV-blocking barriers • Melons as a trap crop for cotton
Integration:				
Develop Integrated Pest Management[c] systems using dual or multiple control tactics, e.g., cultural, biological, chemical, host plant resistance, etc.	Continue field testing & evaluate feasibility of large scale testing; add components as necessary.	X		Much progress with integrating control tactics: • Life table evaluation of both natural and insecticide-based mortalities • Compatibility of IGR's for whitefly control in greenhouses • IPM development in cotton for *Bemisia* and other cotton pests • Augmentative biocontrol using crop transplants inoculated with parasitoids in Admire®-treated fields
Integrate sampling with other key components of IPM systems, e.g., thresholds, economics, decision-making, biological control, etc.	Integrate additional control components into sampling, threshold & decision-making systems	X		• Fourth consecutive year of monitoring *Bemisia* populations in the Imperial Valley using the CC trap. • Sampling-based refinement of action thresholds for IGR's in Arizona cotton

Table F. Integrated and Areawide Pest Management Approaches, and Crop Management Systems. (Continued)

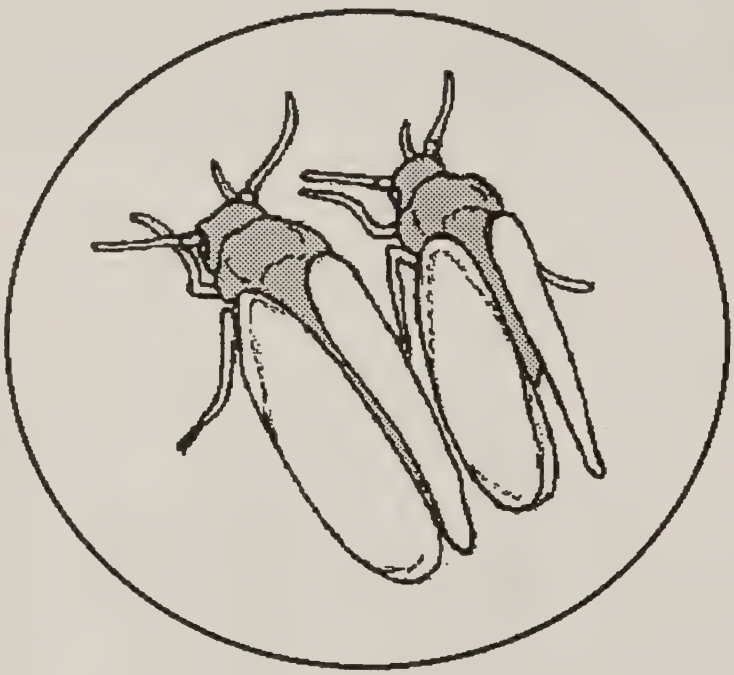
Research Approaches[a]	Year 3 Goals Statement	Progress Achieved Yes	Progress Achieved No	Significance
Delivery and Implementation:				
Elevate single field/farm practices to areawide community-based contexts; develop methodology for installing and evaluating areawide control technologies and their impact.	Identify additional IPM/ICM compatible components. Re-assess and adapt program. Conduct areawide economic analyses.	X		• Economic analysis of the use of IGR's in Arizona cotton • Further development of cross-commodity planning and cooperation • Multivariate techniques used to assess parasitoid establishment in the Imperial Valley based on crop and land use
Implement and deliver Integrated Pest Management and Integrated Crop Management systems or system components to clientele.	Expand sites of testing with grower cooperators; conduct validation studies.	X		• Sticky cotton bulletin published by University of Arizona and Cotton Incorporated • International development of IPM for managing whiteflies and geminiviruses • Development of *Bemisia*-resistant alfalfa cultivars • Crop and pest management demonstration project on cotton in Arizona

[a] See Tables A to E for additional complementary research.
[b] See Tables A for additional complementary research.
[c] See Tables E for additional complementary research.

ADDENDUM

Bibliography of

Bemisia tabaci (Gennadius)
&
Bemisia argentifolii Bellows and Perring



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January 2000

Bibliography of *Bemisia tabaci* (Gennadius) and *Bemisia argentifolii* Bellows & Perring

Addendum, January 2000

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In 1995 we published a bibliography of *Bemisia tabaci* (Gennadius) and *Bemisia argentifolii* Bellows & Perring (Butler et al. 1995). This bibliography was compiled from various sources including the current awareness literature service of the National Agricultural Library, Current Contents (Institute for Scientific Information), the two published bibliographies of Cock (CAB International), and the proceedings of several international conferences and symposia. It attempted to cover the world literature through the end of 1994. Addenda to this bibliography were published in 1996, 1997, 1998 and 1999 (Naranjo et al. 1996, 1997, 1998, 1999). This 5th addendum includes citations listed during 1999.

We alert users of this bibliography to several points. First, we have not attempted to abbreviate many of the names of non-US publications and have spelled out some names, especially USA state names. Second, we have not been able to obtain copies of some of the citations and so could not verify spelling, scientific names, irregular punctuation, and accuracy of the location of the reference. We have tried to standardize as much as possible, but our references may not be exactly as given in the original publications.

To simplify the distribution of electronic copies, we maintain the January 2000 addendum and the total bibliography (through January 2000). This permits those with the complete database from last year to update through the end of 1999 and those without any of the versions to obtain the entire bibliography. We offer several options for obtaining electronic copies. For those that send us a blank diskette and mailer, we will provide copies of the databases in Procite format (please specify *V. 2.*for DOS or *V. 4.03* for Windows 95) word processor format (Word 7.0) or ASCII text format. We can also provide the databases along with a runtime version of the Procite software (please specify *V. 2* for DOS or *V. 4.03* for Windows 95). This runtime software will enable you to search and print the database. Finally, you can download any of the formats mentioned above from the Western Cotton Research Laboratory World-Wide-Web Homepage, **http://pwa.ars.usda.gov/wcrl/**. Comments and suggestions can be addressed to SEN at **snaranjo@ix.netcom.com**

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Appendix B: Meeting Agenda

THIRD ANNUAL PROGRESS REVIEW OF THE FIVE-YEAR SILVERLEAF WHITEFLY RESEARCH, ACTION, AND TECHNOLOGY TRANSFER PLAN
AGENDA

<u>Sunday, February 6, 2000</u>

10:00 a.m.	Poster set-up (PACIFIC BALLROOM C) Registration Begins (PACIFIC BALLROOM LOBBY)	
1:00 p.m.	Meeting Begins (PACIFIC BALLROOM D) Welcome and Announcements	*Walker Jones & Thomas M. Perring*
1:15 p.m.	Charge to Conference	*Thomas J. Henneberry & Robert M. Faust*
1:30 p.m.	Status of the Silverleaf Whitefly in the U.S.	*Thomas M. Perring & Walker Jones*
2:00 p.m.	Section D—Paper Presentations	Co-Chairs: *James Hagler & Matt Ciomperlik*
3:00 p.m.	Break	
3:15 p.m.	Section D—Paper Presentations (continued)	
4:45 p.m.	Section D—Discussion	
5:30 p.m.	Mixer and Poster Session (PACIFIC BALLROOM C)	

<u>Monday, February 7, 2000</u>

7:00 a.m.	Continental Breakfast (PACIFIC BALLROOM D)	
8:00 a.m.	Section C—Paper Presentations	Co-Chairs: *James Brazzle & John Palumbo*
10:00 a.m.	Section C—Discussion	
10:20 a.m.	Break	
10:30 a.m.	Section E—Paper Presentations	Co-Chairs: *Cindy McKenzie & Greg Walker*
noon	Section E—Discussion	
12:20 p.m.	Lunch	
1:30 p.m.	Section F—Paper Presentations	Co-Chairs: *Steve Castle & William Roltsch*
3:25 p.m.	Break	
3:35 p.m.	Section F—Discussion	
3:50 p.m.	Section B—Paper Presentations	Co-Chairs: *Bob Gilbertson & Robin Huettel*
5:50 p.m.	Section B—Discussion	

Tuesday, February 8, 2000

7:00 a.m.	Continental Breakfast (PACIFIC BALLROOM D)	
8:00 a.m.	Section A—Paper Presentations	Co-Chairs: *Tom Perring & Michael Salvucci*
10:00 a.m.	Break	
10:15 a.m.	Section A—Paper Presentations (continued)	
11:00 a.m.	Section A—Discussion	
11:30 a.m.	Lunch	
1:15 p.m.	Silverleaf Whitefly Progress Review	
5:00 p.m.	Progress Review Adjourns Working Group Meeting Begins (WICKER ROOM)	

Immediately following the Working Group, the PPRC will meet.

Section A: Biology, Ecology, and Population Dynamics
Co-Chairs: Thomas M. Perring and Michael E. Salvucci

New Genes and New Signals: The Bemisia argentifolii-Squash Interaction
Linda L. Walling

Do Silverleaf Whiteflies Use Leaf Surface Cues for Feeding Site Selection?
Chu, C.C., T.J. Henneberry, T. Freeman, J. Buckner & D. Nelson

Determination of Stylet Length and the Extent of Stylet Penetration for Silverleaf Whiteflies
Freeman, T., J. Buckner, D. Nelson, C.C. Chu & T.J. Henneberry

The Influence of Nutritional Components on Development and Feeding Behavior of B. Tabaci
Blackmer, J.L.

Effect of Dietary Sucrose Concentration and Temperature on Respiration in Whiteflies
Salvucci, M.E. & S.J. Crafts-Brandner

Relationships Between Nutrition and Free Amino Acid Content of Silverleaf Whiteflies and Their Honeydew
Crafts-Brandner, S.J.

Ecdysteroid Regulation of Molting in 4th Instars of the Greenhouse (Trialeurodes vaporariorum) and Silverleaf (Bemisia argentifolii) Whiteflies
Gelman, D.B. & M.B. Blackburn

Localization of Whitefly Enzymes
Funk, J.

Development of a Transposable Element-based Transformation System for Whitefly
LeVesque, C.

Section B: Viruses, Epidemiology, & Virus-Vector Interactions
Co-Chairs: Robert Gilbertson and Robin Huettel

Tomato Yellow Leaf Curl Geminivirus: A Sexually-Transmitted Disease of Whiteflies?
Hanokh Czosnek

The Effect of Tomato Yellow Leaf Curl Virus (TYLCV) Resistant Tomato Plants on Virus Epidemiology
Lapidot, M.

A New Bipartite Geminivirus (Begomovirus) Causing Cucurbit Leaf Curl and Crumpling Symptoms in the Imperial Valley of California
Gilbertson, R.L.

Differential Transmission Characteristics Among Four Whitefly Vectors of Tomato Chlorosis Crinivirus
Wisler, G.C.

Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods
Co-Chairs: James Brazzle and John Palumbo

Comparative Effectiveness of Rimon with Other Insecticides in Controlling Silverleaf Whitefly
Seal, D.

Control of Whiteflies in Cotton with the Fungi: Beauveria bassiana as Naturalis® and Mycotrol® and Paecilomyces fumosoroseus as PFR-97®
Akey, D.H. & T.J. Henneberry

Incorporating Various Neonicotinoids in Chemical Control Practices for Whitefly Management
Prabhaker, N., N.C. Toscano, S.J. Castle & T.J. Henneberry

Relative Performance of Chloronicotinyl Insecticides in Vegetables and Melons
Palumbo, J.

Biochemical Studies on Imidacloprid and Thiamethoxam Resistant Whiteflies
Byrne, F.J.

New Products and FQPA: How Will Chemical Control and Resistance Management Change?
Nick Toscano, James Brazzle and John Palumbo

Section D: Natural Enemy Ecology and Biological Control
Co-Chairs: Matthew Ciomperlik and James Hagler

Species of Eretmocerus
Mike Rose

Morphological, Molecular and Taxonomic Perspectives on Encarsia Attacking Whiteflies
John Heraty

Assessing the Impact of Established Whitefly Parasitoids in the Imperial Valley Using Multivariate Techniques
Andress, E., J. Gould & M. Quinn

Comparision of Four Methods of Releasing Whitefly Parasitoids: Survival, Dispersal, and Mating Success
Gould, J.

Classical Biological Control Update for Imperial Valley
Roltsch, W.

Releases of Exotic Parasites and the Citrus/Cotton Interface in Central California
Pickett, C.H

Development of Encarsia formosa in the Silverleaf Whitefly, Bemisia argentifolii: Effect of Host Age
Hu, J.S. & D.B. Gelman

Bionomics and Population Dynamics of Encarsia transvena
Palaniswami, M.S.

Transmission of Fungal Biocontrol Agents
James, R.R.

Section E: Host Plant Resistance, Physiological Disorders, and Host-Plant Interactions
Co-Chairs: Cindy McKenzie and Greg Walker

Behavioral Response of Silverleaf Whitefly Adult Females to Plant Species Varying in Host Suitability
Walker, G., D. Johnson & H. Costa

Probing and Feeding Behavior of Bemisia tabaci on Two Isogenic Tomato Lines
Jiang, Y.X., M. Muñiz, & A. Fereres

Whitefly Feeding Induces Local and Systemic Changes in Tomato Gene Expression
Walling, L.L., D. Puthoff & T.M. Perring

Characterization of Squash Genes Induced by Silverleaf Whitefly Infestation
Van de Ven, W.T.G., T.M. Perring & L.L. Walling

Cotton Leaf Crumple Disease Resistance in Cotton
Natwick, E.

Section F: Integrated and Areawide Pest Management Approaches, and Crop Management Systems
Co-Chairs: Steve Castle and William Roltsch

Whitefly Population Dynamics: Why Use Life Tables and What Do They Tell You?
Part I: Steve Naranjo and Part II: Peter Ellsworth

Compatibility of Selected Insect Growth Regulating Insecticides with the Whitefly Parasitoid Eretmocerus eremicus for Control of Bemisia argentifolii on Poinsettias
Hoddle, M.S., R.G. Van Driesche, S.M. Lyon & J.P. Sanderson

CGIAR Whitefly IPM Project
Anderson, P.K.

Efficiency of Living Ground Covers to Manage Whiteflies as Vectors of Geminiviruses in Tomato
Hilje, L. & P.A. Stansly

Concentration and Management of Whiteflies in Melons as a Trap Crop for Cotton
Castle, S.J.

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Minutes of the Silverleaf Whitefly (SLWF) Working Group Meeting

February 8, 2000, 3:30-4:30 p.m.
Holiday Inn on the Bay, San Diego, CA

Introductory Remarks
The meeting was called to order by Walker Jones. He distributed an attendance sheet, discussed the overall objectives for the Working Group meeting and reviewed the agenda. He inquired about the US Department of Agriculture funding to help support the annual progress reviews. $11,497 was transferred to the Western Cotton Research Laboratory, Phoenix, AZ for registration fees, speaker travel and to help defray costs. Western Cotton Research Laboratory transferred $5,000 to the University of California for that purpose. Tom Perring asked if the funds could be used for next year's meeting.

Report of Meeting Attendance
In attendance this year were 80 registrants including the working staff. Foreign visitors were from Costa Rica (1), Dominican Republic (1), India (1), Israel (2), Mexico (2), Chile (1), and Columbia (2).

Working Group Critique of Workshop and Suggestions for the PPRC
Walker Jones stated that last year the working group suggested that it would be useful to have someone give "state of the silverleaf whitefly" reports for each State in future meeting plenary sessions (or in Section F). These reports would be general and become part of the formal program report.

Ian Wedderspoon will continue to solicit industry support for the meeting as well as participation in the meeting.

The group recommended that the 5-year plan tables be included as a part of the opening day packet.

It was recommended that we continue with the plenary session format for the meeting. Steve Naranjo indicated that there was no time available for discussion. Some suggestions included focusing presentations to stimulate discussions and formalizing the discussion section. Section Chairs asked that there not be breaks in between section papers and the discussion period. Talk times should be assigned on the agenda. A suggestion was to have speakers come to the front and act as a panel during the discussion period. Bring light box/timer to keep the speakers on time.

The group discussed the necessity for completing the tables at the end of the meeting. A suggestion was made to focus discussions to a theme by specifying papers to the tables. The co-chairs could solicit topics and ask for technology transfer as a summary. Robin Huettel suggested that co-chairs fill out the tables and see if there is anything to add. Ian Wedderspoon stated that it forces the group to see what has been done. It is a good way of wrapping up the session and it helps solidify the program for next year.

Mike Salvucci noted that some of the symposium speakers had posters as well. It might be helpful if they had handouts. It was suggested that all speakers also be asked to give posters.

Ian Wedderspoon asked if the abstracts could be posted on the internet. Peter Ellsworth posted last year's already and asked Marla to send him the abstracts for this year.

The group asked if the meeting could be held at an airline hub city to save airfare costs. Some suggestions for next year's meeting were Dallas/San Antonio, San Diego, Miami/Orlando.

Other Business
A deadline of February 25, 2000, was set for receipt of all corrected and/or additional abstracts. All technology transfer/progress review summaries and year 3 tables for the 2000 Progress Review and Technology Transfer Report are due by March 10, 2000.

Information should be sent to:
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The information listed above should be transmitted either on disk with a hard copy or via-e-mail with a hard copy in Word97 or Wordperfect 6.0.

The minutes for the Working Group meeting will be transcribed by Marla Lawrence and then sent to Walker Jones for review. The minutes will be included as an Appendix in the 2000 SLWF Progress Review and Technology Transfer Report.

Walker Jones adjourned the Working Group meeting at approximately 4:30 p.m.

Respectfully submitted,

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Enclosures:
- SLWF Working Group Meeting Attendees
- SLWF Working Group Agenda

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Minutes
PPRC Meeting
Holiday Inn on the Bay
2/6/00
11:30 a.m.

Meeting was chaired by Tom Perring and Lisa Arth. PPRC members in attendance were:

Lisa Arth	James Brazzle	Steve Castle	Matt Ciomperlik
Robert Faust	Cindy Giorgio	James Hagler	Thomas Henneberry
Robin Huettel	Walker Jones	Marla Lawrence	Cindy McKenzie
John Palumbo	Tom Perring	Bill Rolsch	Mike Salvucci
Nick Toscano	Greg Walker		

Lisa Arth discussed the general overview of the program and reminded Section Co-chairs of their assignments during the meeting which included: 1) keeping the scheduled talks on time, 2) leading discussions, and 3) updating year 3 tables during the progress review.

Lisa reminded Section Co-chairs that after the meeting they must submit section summaries with technology transfer and completed year 3 tables to Marla Lawrence.

Marla Lawrence will send co-chairs all copies of abstracts by February 28th.

Deadlines for abstracts submission or changes will be February 25th and Section Chair information is due to Marla Lawrence by March 10th.

Lisa asked current section chairs to be prepared to recommend co-chairs to the Program Planning Review Committee.

Tom Perring asked the committee to consider a status project on the impact of the whitefly. Nick Toscano suggested that it could be a symposium on exotic pest outbreaks at the annual ESA meeting. Robin Huettel suggested possible funding from the Invasive Species Advisory Council to support the status project. There is $15 million in competitive grants available through CSREES.

The next PPRC meeting will be held after the Technical Working Group Meeting. Co-chairs were asked to be thinking about next year's meeting dates and location.

Minutes
PPRC Meeting
Holiday Inn on the Bay
2/8/00

Meeting was chaired by Lisa Arth and Tom Perring. Members in attendance were:

Lisa Arth	James Brazzle	Steve Castle	Matt Ciomperlik
Peter Ellsworth	Tom Henneberry	Robin Huettel	Marla Lawrence
Cindy McKenzie	Steve Naranjo	John Palumbo	Tom Perring
Bill Roltsch	Mike Salvucci	Greg Walker	Ian Wedderspoon

Lisa Arth asked that the section chairs insure that keynote addresses be sent to Marla for the publication. All keynote speaker travel costs should be submitted to Lisa. She also asked that the committee review the recommendations about dates, location and structure of the next progress review.

The group decided to try Tucson, Arizona for the meeting in 2001. Lisa will check on some meeting sites to see if there is anything suitable. If Tucson cannot meet reasonable lodging rates for that time of year, the meeting will be held again in San Diego, CA during the 1st week in February.

The meeting format will be Sunday through Tuesday with an afternoon start. The structure will be plenary, if possible, depending on number of submissions. This will be determined by the Committee at such time as necessary. It will remain at 2 ½ days and the progress review will continue to be held at the end of the meeting. Section A will continue to be on the last day.

Lisa Arth requested the section chairs submit replacements for the 2000 meeting:

Section A	Mike Salvucci	Tom Perring
Section B	Robin Huettel	Bob Gilbertson
Section C	Shirley Taylor	John Palumbo
Section D	Matt Ciomperlik	Bill Roltsch
Section E	Greg Walker	Cindy McKenzie
Section F	Steve Castle	Luko Hilje

The Section Chairs need to insure that final replacements are submitted to Lisa Arth no later than May 31, 2000
A reminder of the deadlines:

Abstracts	25 February
Year 3 Tables	10 March
Section summary/technology transfer	10 March
Keynote speaker summary	10 March
Revisions to 5-year table	10 March

Silverleaf Whitefly Working Group Meeting
February 8, 2000
San Diego, California
3:30 - 4:30 p.m.

Walker Jones, USDA-ARS, Presiding

AGENDA

• Introductory Remarks/Old Business	W. Jones
• Report of Meeting Attendance	L. Arth
• Working Group Critique of Workshop & Suggestions for the PPRC	Group
• 2000 Program Review Report	Arth/Perring/Jones
• Other Items	Group
• Adjourn	

Five-Year National Research and Action Plan Priority Tables, Research Needs, and Yearly Goals (1997-2001)

Table A. Biology, Ecology, and Population Dynamics

Approaches/Goals	Year 1	Year 2	Year 3	Year 4	Year 5
Determine life cycle vulnerabilities (life tables)[a], population development and natural mortality factors, natural enemies on major crops, urban plantings, weeds and predict overwintering potential.	Whitefly and natural enemy sampling in cultivated crops, urban planting and weed hosts.	Determine potential of intercrop weed host & urban planting, movement of whiteflies and natural enemies.	Identify potential low population manipulation on vital host links for survival.	Initiate studies to manipulate host sequences to determine potential influence on whitefly population.	Continue 4 and finalize analysis of the potential of habitat modification as a management tool.
Develop sampling methodology, action and[b,c] economic thresholds for all major crops. Sampling methods and thresholds modified in light of natural enemy levels and existing management strategies.	Initiate whitefly to identify spatial and temporal distributions in major cultivated crops.	Analysis and identification of needed additional sampling research to develop appropriate sampling protocol.	Validate and refine sampling methods.	Implement sampling protocols through cooperative extension outlets and other technology transfer methods.	Finalization, implementation and use in IPM systems.
Develop population models to describe and predict whitefly population growth and spatial and temporal distribution. Develop simple day-degree sub-models for estimating phenology and temporal patterns of whitefly, natural enemies and host crops.	Summarize whitefly biology, ecology and plant phenology to identify whitefly host plant interfaces.	Begin model development to include all biological and plant phenology data in simulation development.	Provide model simulation of whitefly populations and multiple cropping systems.	Identify weak points and needed information to improve model simulations.	Validate and expand effort to provide predictive models capabilities for whitefly population development and crop interfaces.
Develop sampling methods for quality of cotton lint, vegetables and other commodities.	Initiate sampling of seed cotton in the field during the season, at harvest, after picking, moduling and ginning.	Based on 1, expand and repeat sampling protocols as described.	Develop sampling protocol for field and harvest and processing sampling and determine interrelationships.	Extend sampling protocols to textile mill and verify field findings in relation to mill problems.	Modify, refine and complete sticky cotton sampling protocols from the field to the mill.
Quantify whitefly and natural enemy dispersals and contribution to population dynamics.	Review and analyze existing knowledge of whitefly dispersal.	Validate times of whitefly dispersal, environmental factors and identify modifying factors.	Determine proportion of whitefly population that are migratory and their reproductive potential.	Quantify the role of dispersal in population dynamics on different crop systems.	Formulate theory for manipulating and/or using dispersal as a tool in IPM.
Define mating behavior, reproductive isolation, species, biotypes.	Initiate studies on mating, oviposition and other behavior.	Define interspecies interbiotype mating interactions.	Define factors involved in mating, cues, feedback mechanisms, etc.	Develop potential methods of utilizing behavioral information in management strategies.	Review, summarize and propose additional needed research.

Table A. Biology, Ecology, and Population Dynamics

Approaches/Goals	Year 1	Year 2	Year 3	Year 4	Year 5
Validate *Bemisia* taxa morphology, genetic, biochemical, and biology characteristics.	Continue examination of *Bemisia* sp. for distinct morphological character differences.	Develop genetic molecular level and acceptable species level separation.	Discuss results, plan additional research, arrive at a consensus decision.	Publish verification of new species or other appropriate taxa.	--------------------------
Define role of endosymbionts in metabolism, host adaptation, nutrition and survival.	Identify endosymbionts in whitefly.	Determine role of endosymbionts in whitefly biological functioning.	Determine potential for manipulating, interfering with or inhibiting endosymbiont function.	Determine associated enzymes and/or other endosymbionts and whitefly relationships.	Summarize and implement findings with suggestion for additional research.
Characterize nutrient uptake and metabolism	Identify the major carbohydrates, amino acids and other nutrients essential for whitefly growth and development.	Determine the biochemical pathways for metabolism of compounds essential for whitefly development.	Determine the physical and biochemical processes involved in uptake of carbohydrates, amino acids and other essential nutrients.	Determine the potential for blocking key steps in nutrient uptake and/or metabolism.	Implement findings by developing inhibitors of nutrient uptake and/or metabolism.
Develop whitefly artificial diets and natural enemy mass-rearing.	Identify whitefly nutritional components in plant tissue.	Develop whitefly artificial feeding systems.	Conduct addition, deletion studies to identify essential nutritional needs.	Evaluate developed diets on whitefly fecundity/longevity biology, behavioral characteristics.	Develop whitefly rearing system and adapt for production of natural enemies.
****Pursue specific genetic and biological basis for variability in whitefly biotypes, strains, and species; determine impact of different genotypes/phenotypes on whitefly-mediated transmission and on the epidemiology of virus diseases.**	Identify differences in species, strains and biotypes with respect to transmission, host range, mating compatibilities, molecular variability, and map the biogeographic distribution of distinct types within the *B. tabaci* species complex.	Continue to study differences in species/ strains/biotypes with respect to transmission, host range, mating compatibilities, molecular variability. Determine molecular basis of observed variability in biological, molecular, & genetic terms. Infer molecular phylogenies from molecular markers.	Continue with work from previous years. Study impact of biotypes, strains, and species differences in the disease spread, crop damage, and specific control measures to reduce whitefly vector populations. Linkages with biological and chemical control sections.	Identify potential factors related to specific genetic and biological variability that may be manipulated to reduce disease spread. Develop molecular approaches to track biotypes, strains, and species relative to disease spread, based on differential molecular markers.	Summarize results, identify new research needs and make recommendations for implementation or expansion of research.

[a] Natural enemy research complements from Section D, see Table D.
[b] Action and economic thresholds also apply in Section C, see Table C.
[c] Sampling technology applicable to all other sections, see Tables B to F.
** Revised 3/31/2000

Table B. Viruses, Epidemiology, and Virus-Vector Interactions

Approaches/Goals	Year 1	Year 2	Year 3	Year 4	Year 5
Identification and characterization of new or emerging whitefly-transmitted viruses and strains	Monitor crops for presence of whitefly-transmitted diseases, and determine relative disease incidence. Begin virus identification and strain differentiation.	Virus identification and characterization. Develop methods for identifying causal agents and for tracking viruses and strains using molecular methods.	Continue etiological studies and virus characterization. Apply molecular diagnostics to virus identification and evaluation of disease incidence and virus distribution.	Continue etiological studies and virus characterization efforts. Apply molecular diagnostics to virus identification and evaluation of disease incidence and virus distribution.	Summarize and review results. Determine areas of new research.
Molecular epidemiology: identification of economic viruses, host plants, and reservoirs, and determination of geographic distribution of viruses.	Monitor and identify host plants, virus reservoirs in affected areas. Linkages to diagnostic methods for virus ID and tracking.	Continue field studies. Determine economic input of diseases on crop production and associated losses.	Establish geographic distribution of viruses and identify sources of inoculum. Assess role of alternative host virus reservoirs on spread of diseases.	Identify and characterize virus involvement in disease establishment and spread. Assess potential methods of reducing virus reservoirs as a method of reducing disease.	Review and make recommendations for further research and potential implementation of results.
Virus-vector interactions, factors affecting virus transmission, and basis for virus-vector specificity; determination of endosymbiont involvement in whitefly-mediated transmission	Initiate studies on virus-vector interactions and on basis for the specificity of whitefly-mediated geminivirus transmission.	Determine specific cellular and molecular factors involved in virus transmission. Study role of endosymbionts in virus acquisition and transmission.	Continue studies in progress to determine specific factors involved in virus transmission, and the role of endosymbionts in virus acquisition and transmission.	Continue virus-vector interactions studies toward the development of approaches for disease control.	Summarize findings and suggest new research needs; implementation of existing knowledge.
Strategies to reduce virus spread by management of cropping systems, reduced transmission frequencies, and other potentially effective approaches.	Develop approaches to managing cropping systems to reduce vector densities to decrease transmission frequency and inoculum sources, taking into account weed and crop reservoirs in disease incidence and distribution.	Continue studies of management approaches for disease abatement. Interdisciplinary studies in conjunction with whitefly control methods in Sections B and C.	Continue studies of management approaches for disease abatement. Focus on interdisciplinary studies in conjunction with whitefly control methods in Sections B and C.	Evaluate strategies for crop management and impact on disease epidemiology.	Evaluate approaches and identify areas of future research for disease control by management of cropping systems. Linkages with IPM approaches.

Table B. Viruses, Epidemiology, and Virus-Vector Interactions (continued)

Approaches/Goals	Year 1	Year 2	Year 3	Year 4	Year 5
Control of virus diseases: development of virus resistant germplasm through conventional and engineered/molecular approaches. Define prospective strategies for selecting candidate viruses, identifying specific virus diseases to target, and prioritize specific crops and cultivars for protection approaches.	Define strategies for resistance efforts. Identify target viruses. Identify germplasm with virus resistance. Initiate efforts toward defining prospective engineered resistance strategies. Identify candidate crops and recipient cultivars.	Continue to define suitable strategies for determining target viruses. Isolate and characterize virus-resistant germplasm. Continue work toward engineered resistance in target crops and selected viruses.	Further identification of resistant germplasm and develop new methods of incorporating resistance into crop plants. Evaluate resistance strategies with respect to broad spectrum or virus-specific protection.	Continue development of resistant varieties. Evaluate resistance strategies with respect to broad spectrum or virus-specific protection. Define mechanisms of resistance.	Evaluate resistant plants in greenhouse and field experimentation, and identify additional research. Molecular-based monitoring of transgenes in environment.

** Revised 3/31/2000

Table C. Chemical Control, Biopesticides , Resistance Management, and Application Methods

Approaches/Goals	Year 1	Year 2	Year 3	Year 4	Year 5
Improve insecticide efficacy:					
• **Develop, test, and assist in the registration of insecticides, biorationals, and natural products.**	Develop new chemistries and natural products. Develop improved techniques for evaluating efficacy of insecticides. Support registration of desirable new products by providing information to regulatory agencies.	Same as Year 1. Determine new modes of action of effective materials. Elucidate biochemical pathways of synthesis and degradation of natural products.	Same as Year 2. Evaluate the potential for transforming plants with natural product genes.	Same as Year 3.	Same as Year 4.
• **Develop improved methods of application including formulation and delivery of materials to improve control.**	Develop spray systems for better underleaf coverage. Evaluate rates, timing, placement in relation to efficacy. Consider formulation, UV protectants, and other means to improve efficacy. Develop improved methods to evaluate application efficacy. Field test under commercial conditions for technology transfer.	Same as Year 1.	Same as Year 2.	Same as Year 3.	Same as Year 4.
Conserve insecticide efficacy:					
• **Relate action thresholds to insecticide usage patterns.**	Refine action thresholds based on insecticide efficacy and input from other control strategies.	Same as Year 1.	Same as Year 2.	Same as Year 3.	Same as Year 4. Summarize and recommend in IPM systems.

Table C. Chemical Control, Biopesticides , Resistance Management, and Application Methods (continued)

Approaches/Goals	Year 1	Year 2	Year 3	Year 4	Year 5
• **Elucidate the role of genetic, biochemical and ecological factors leading to insecticide resistance.**	Establish whitefly strains resistant and susceptible to various classes of insecticide. Conduct studies to determine the genetics and biochemistry of resistance and cross resistance to different classes of insecticide.	Same as Year 1. Evaluate the role of refuge habitats (weeds, tolerant crops, urban areas) to assure input of susceptible genes in whitefly population.	Conduct studies to determine the genetics and biochemistry of resistance and cross resistance to different classes of insecticide. Evaluate the role of refuge habitats (weeds, tolerant crops, urban areas) to assure input of susceptible genes in whitefly population. Evaluate the influence of host plant on susceptibility to insecticides.	Same as Year 3.	Same as Year 4.
Improve insecticide efficacy:					
Improve techniques for monitoring resistance.	Establish baseline data on toxogenic responses of whitefly populations to new insecticides.	Same as Year 1. Expand comparative studies of resistance levels in diverse agro-ecosystems. Evaluate relationship between monitoring results and field efficacy.	Same as Year 2. Summarize, analyze, and produce standardized comparable monitoring systems.	Same as Year 3. Develop standard systems for general use including user friendly techniques to assist growers and extension agents to evaluate susceptibility of whitefly populations to commonly used insecticides.	Same as Year 4.
Develop, evaluate and refine resistance management systems	Evaluate the effects of mixtures and rotations of new and old chemistries to mitigate selection for resistance.	Same as Year 1. Develop methods to evaluate and augment the beneficial influence of refuges as sources of susceptible genes to the population pool.	Same as Year 2. Develop criteria for integration of successful strategies in agricultural systems. Field test resistance management systems as long range components of successful IPM.	Same as Year 3.	

Table C. Chemical Control, Biopesticides , Resistance Management, and Application Methods (continued)

Approaches/Goals	Year 1	Year 2	Year 3	Year 4	Year 5
					Same as Year 4. Technology transfer.
Integrate chemical control with other tactics.	Evaluate selectivity of synthetic insecticides and natural products to key whitefly natural enemies.	Same as Year 1. Test compatibility of biological control with selective synthetic or natural product insecticides as required.	Same as Year 2. Integrate systems with host plant resistance and cultural controls.	Test compatibility of biological control with selective synthetic or natural product insecticides as required. Integrate systems with host plant resistance and cultural controls.	Integrate systems with host plant resistance and cultural controls. Summarization and technology transfer.

[a] See Table A for complementary research on thresholds.
[a] See Table B for complementary research on virus/vector interactions.
[a] See Table D for complementary research on biological control.
[b] See Tables E and F for complementary research on systems management.

Table D. Natural Enemy Ecology and Biological Control

Approaches/Goals[a]	Year 1	Year 2	Year 3	Year 4	Year 5
Natural control and conservation:					
• **Develop natural enemy conservation practices to reduce mortality to indigenous and introduced natural enemies.**	Conduct life table analyses of indigenous and introduced natural enemies to identify key mortality factors of natural enemy populations.	Identify the spatial scale upon which the key mortality agents are acting.	Conduct manipulative experiments to evaluate the impact of each natural enemy mortality agent on whitefly suppression.	Conduct a feasibility study and economic assessment of altered crop management practices that may enhance the impact of indigenous natural enemies.	Develop and evaluate area wide programs to facilitate full implementation.
• **Evaluate potential of alternate plants it act as in-field refuges or insectaries for natural enemies.**	Identify potential plants for natural enemy population development and assess risks of these plants to foster additional pest problems.	Determine refugia plant phenology in relation to cultivated crop phenology.	Conduct field tests to assess whether refuges act of natural enemy and whitefly sinks or sources to adjacent cropping systems.	Conduct field tests to evaluate spacing of refuges necessary to achieve satisfactory whitefly suppression.	Conduct a feasibility study and economic assessment of alternate plantings in terms of an entire crop management program.
• **Assess cues used by natural enemies to locate whitefly to identify potential methods for enhancing natural enemy activity.**	Conduct laboratory tests to identify cues used by natural enemies to locate and attack whitefly.	Determine potential methods for manipulating cues as part of a whitefly management program.	Conduct small scale trials to enhance whitefly suppression by manipulating natural enemy location and attack of whitefly.	Conduct large scale field trials and evaluate product development for commercial investment as necessary.	Transfer technology (as needed) to commercial interests for full implementation.
Augmentation of natural enemies:					
• **Develop natural enemy mass-rearing systems.**	Identify natural enemies with the highest potential for controlling whitefly in key cropping systems.	Determine nutritional, physiological, and ecological requirements for mass-rearing.	Develop rearing systems on selected hosts and on artificial diets. Determine economic feasibility of the procedure.	Evaluate rearing system effects on natural enemy life history characteristics, behavior, and ability to suppress whitefly populations.	Facilitate transfer of mass-rearing technology to commercial interests as necessary.

Table D. Natural Enemy Ecology and Biological Control (continued)

Approaches/Goals[a]	Year 1	Year 2	Year 3	Year 4	Year 5
Importation biological control:					
• **Develop release technologies to maximize the effectiveness of mass-reared natural enemies in the field.**	Identify natural enemies with the highest potential for controlling whitefly in key cropping systems and that may be economically mass produced.	Evaluate the fate of natural enemy life stages under field conditions to identify the appropriate developmental stage to be released.	Develop necessary technology for release of the appropriate natural enemy life stage.	Evaluate release technology effects on natural enemy life history characteristics, behavior, and ability to suppress whitefly populations.	Facilitate transfer of mass-rearing technology to commercial interests as necessary.
• **Evaluate augmentative parasitoid, predator, or pathogen releases.**	Initiate studies on natural enemy augmentation with identified high potential natural enemies.	Conduct releases on selected crop systems at various rates of release.	Identify optimal release strategies for key cropping systems.	Continue evaluation of releases, determine need for additional releases. Compare results in different cropping systems and environments.	Analyze information and make recommendation regarding need for expansion of the approach.
• **Evaluate the ability of exotic natural enemies to suppress whitefly populations under field conditions.**	Identify sites suitable for the release and subsequent evaluation of each candidate natural enemy. Conduct inoculative releases of natural enemies.	Evaluate establishment of exotic natural enemies within target release area. Determine if additional releases are necessary.	Assess spread of established natural enemies and their ability to suppress whitefly populations.	Continue to assess the spread of established natural enemies and their ability to suppress whitefly populations. Evaluate program progress and determine if additional strategies are necessary.	Complete program analysis. Publish program assessment and conduct an economic assessment.
• **Clarify systematics of predators, parasitoids and pathogens.**	Conduct taxonomic studies of species within targeted release sites. Verify taxonomic purity of mass-reared natural enemies. Complete taxonomic work on poorly characterized but important groups. Assist in determining most suitable natural enemies for release through biogeographical analysis	Provide taxonomic support for importation and mass-rearing programs. Publish keys to assist in species identifications.	Provide taxonomic support for importation and mass-rearing programs.	Provide taxonomic support for importation and mass-rearing programs.	Provide taxonomic support for importation and mass-rearing programs.

Table D. Natural Enemy Ecology and Biological Control (continued)

Approaches/Goals[a]	Year 1	Year 2	Year 3	Year 4	Year 5
Systematics, ecology, and population dynamics of natural enemies[b]:					
• **Determine *Bemisia* - natural enemy-host plant (Tritrophic) interactions.**	Initiate studies to identify mechanisms involved in *Bemisia* - and natural enemy plant attraction.	Study plant characteristics mediating whitefly population densities.	Study compatibility of characteristics of plant traits mediating whitefly populations with the abilities of natural enemies to suppress whitefly populations.	Assess the implementability of favorable tritrophic interactions within the context of an whitefly management program.	Implement and evaluate large scale crop management programs for suppression of whitefly populations.
• **Identify the attributes of natural enemy biology and population level interactions to explain biological control successes and failures.**	Assess the value of the *Bemisia* biological control research to evaluate key issues to the science of biological control.	In conjunction with field evaluations, validate predictions made by behavioral and population models important to biological control.	Assess deviations between theoretical predictions and field data.	Evaluate behavioral or population level parameters that may explain observed deviations.	Quantify the impact of basic research on the development of feasible biological control programs for *Bemisia* and the advancement of the field as a science.

[a] See Table C for complementary research.
[b] See Table A for complementary research.

Table E. Host Plant Resistance, Physiological Disorders, and Host Plant Interactions

Approaches/Goals	Year 1	Year 2	Year 3	Year 4	Year 5
Characterize resistance mechanisms and identify chemical/morphological components, and study effects of insect adaptation.	Identify potential sources of germplasm for disease, plant disorders and whitefly resistance.[a]	Determine physiological and/or morphological basis for resistance, & effects of host-plant history and insect adaptation on plant resistance to whiteflies. Continue to identify resistant germplasm.	Elucidate biochemical and molecular basis for resistance. Continue to identify resistant germplasm.	Determine potential for transfer of resistance traits.	Evaluate potential for incorporating *Bemisia*, plant disorder and disease resistance into acceptable plant type.
Develop molecular level techniques to produce resistant germplasm.	Identify physiological processes of whiteflies to target for inhibition.	Identify natural products for inhibiting processes.	Isolate the relevant biosynthetic enzymes that encode for natural products inhibiting processes.	Insert genes into plants via plant transformation.[b]	Evaluate potential of newly transformed germplasm.
Incorporate resistance traits into commercial genotypes.	Identify and isolate genetic sources of resistance for transformation and/or breeding.	Insert genes into plants[b] via plant transformation.	Evaluate potential of newly transformed germplasm.	Continue to refine resistance factors to improve resistance in newly transformed germplasm.	Incorporate other desirable plant characteristics for crop production.
Determine influence of host plant morphology, physiology and phenology on feeding behavior and competition.[c]	Characterize nutritional and other preference properties of various host plants.	Determine the biochemical mechanism regulating adaptation to host plants.	Determine changes in whitefly gene expression in response to host manipulation.	Relate changes in gene expression to whitefly physiology.	Summarize and disseminate results.
Define whitefly feeding and oviposition behavior and investigate approaches for interrupting whitefly feeding and digestion.[d]	Investigate approaches for interruption of feeding, assimilation, development and reproduction.	Identify physiological and morphological mechanisms regulating processes.	Determine biochemical and molecular basis for inhibiting processes.	Determine potential for transfer of resistance traits.	Insert genes into plants[a] via plant transformation.
Study whitefly toxicogenic plant reactions.	Determine effects of whitefly feeding on host plant physiology, morphology and anatomy.	Determine biochemical basis for physiological response of plant.	Elucidate changes in plant gene expression.	Identify resistance germplasm.	Evaluate potential for transferring new germplasm.

[a] See Table B for additional plant disease resistance research.
[b] Progress at this point may extend to several year research.
[c] See Section A.
[d] See Section A, approach #9.

Table F. Integrated and Areawide Pest Management Approaches and Crop Management Systems

Approaches/Goals[a]	Year 1	Year 2	Year 3	Year 4	Year 5
Development:					
Study whitefly-crop interactions[b] as cultural components that affect population dynamics, e.g., water, nutrients, plant population, planting/ termination/harvest dates, other farm practices, intercrop relationships.	Identify potential beneficial or exacerbating farm practices or inputs for testing.	Determine nature and character of relationship between interaction and whitefly population dynamics.	Identify mechanisms governing relationship and alter or manipulate factors that suppress whitefly dynamics.	Refine system, add other compatible components, evaluate economic impact; conduct field testing and evaluations.	Conduct economic analyses and determine next level of IPM/ICM systems evaluation. Develop recommendations of best management practices.
Develop behavioral barriers[b] to whitefly colonization and population development, e.g., mulches, trap crops, intercropping, row covers, etc.	Review potential behavioral disrupters and evaluate as potential IPM components.	Conduct field-level trials; quantify impact to crop and whitefly dynamics	Apply promising technologies to high-value crop systems; field test and evaluate.	Refine system, add other components, and conduct economic feasibility analyses.	Summarize and evaluate results; prepare crop systems-specific recommendations.
Integration:					
Develop Integrated Pest Management[c] systems using dual or multiple control tactics, e.g., cultural, biological, chemical, host plant resistance, etc.	Identify candidate dual or multiple control tactic systems, e.g., IGRs and natural enemy conservation.	Initiate field testing of candidate systems.	Continue field testing & evaluate feasibility of large scale testing; add components as necessary.	Initiate large-scale experiments; incorporate economic evaluation.	Evaluate multiple component system as potential deliverable; prepare recommendations.
Integrate sampling with other key components of IPM systems, e.g., thresholds, economics, decision-making, biological control, etc.	Develop or modify sampling systems for new crops; integrate with thresholds and decision-making.	Establish practical utility of system through economic analyses; field efficiencies and costs.	Integrate additional control components into sampling, threshold & decision-making systems	Evaluate in whole field systems. Identify weaknesses; target improvements.	Evaluate redesigned decision systems; continue field testing and economic analyses.
Delivery and Implementation:					
Elevate single field/farm practices to areawide community-based contexts; develop methodology for installing and evaluating areawide control technologies and their impact.	Identify agricultural communities amenable to areawide management; conduct thorough pre-implementation evaluation.	Install control technologies into community; develop systems for evaluation.	Identify additional IPM/ICM compatible components. Re-assess and adapt program. Conduct areawide economic analyses.	Formulate clientele surveys; develop & begin to implement protocols for evaluating areawide technologies.	Refine, reevaluate and identify weaknesses. Formulate recommendations for future areawide management systems. Conduct surveys.

Table F. Integrated and Areawide Pest Management Approaches and Crop Management Systems

Approaches/Goals[a]	Year 1	Year 2	Year 3	Year 4	Year 5
Implement and deliver Integrated Pest Management and Integrated Crop Management systems or system components to clientele.	Develop and distribute provisional IPM & ICM recommendations.	Conduct whole farm/operation demonstrations of IPM systems.	Expand sites of testing with grower cooperators; conduct validation studies.	Incorporate new information and economics into recommendations.	Validate new components; finalize recommendations; expand to new crops.

[a] See Tables A to E for additional complementary research.
[b] See Table A for additional complementary research.
[c] See Table E for additional complementary research.